OPTICAL DENSITY SENSOR REPLACEMENT

Second Semester Report
Spring Semester 2009

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ABSTRACT

The purpose of this senior design project is to create a replacement optical density sensor for Solix Biofuels. Solix Biofuels is a company which grows algae to turn into biodiesel. Solix uses these sensors to measure the biomass of the algae, which tells them when the algae are ready to be harvested. The problem that they find with current optical density sensors are that they are costly and this makes them not practical for their future commercial production designs. Another problem is that they currently have been testing in-situ sensors which are prone to fowling which in turn affects the sensor data.

Our senior design project has focused on replicating the current optical density sensors that Solix Biofuels is using in their daily operations. We have done this by using and experimenting with photodiodes and phototransistors that operate in the near infra-red range spanning from 850-940 nm.

The final prototype created is a portable, hand held, battery powered sensor that uses a 850 nm LED and matching phototransistor. The sensor can be placed over the bags used to grow algae instead of inside. The prototype also contains a display that outputs the dry mass of the algae (G/L) as a function of voltage.

Table of Contents

List of Figures and Tables

Figures

Tables

I. Introduction

The purpose of this senior design project is to design a replacement optical density sensor for Solix Biofuels. This paper will outline

- Solix's need for a replacement sensor.
- The restraints placed on our design.
- The research we conducted on creating our current designs.
- Our prototype designs and our current configuration.
- What plans we have for the future of this project.

Background on Solix Biofuels

Solix Biofuels is a company that was started in 2006. It is currently focused on the development and commercialization of large-scale algae-to-biofuels system. Its intellectual property is in reactor technology, controls, biology, and downstream processing. It is currently the second largest producer if algae.

As part of Solix Biofuels operations they use optical density sensors to measure the biomass of algae contained in their bio-reactors. The biomass of the algae determines when the algae are ready to be harvested from their reactors and ready to be processed.

The problems with their current optical density sensors include:

- Cost: The current model of optical density sensor is to expensive to be implemented in a large scale production operation
- Placement: The current sensor they use in production is an in-situ sensor and is prone to fouling.

Design Restraints

The current design restraints that Solix Biofuels has placed on the design of the optical density sensor include:

- Cost: Creating an optical density sensor that costs significantly less than the current sensor that they are using in production.
- Placement: To avoid the problem of fouling the sensor needs to be mounted on the outside of the reactors containing the algae.
- Consistency: The current optical density sensor that is being used operates in the NIR range from 840-910 nm. The biology team uses equipment that measures biomass at 750nm. Our sensor should operate in these ranges to be consistent with their current sensors so that we can compare our results with the biology teams results.
- Portability: The sensor needs to be a hand held portable device with a display

This is just a brief overview of what we as a group are trying to accomplish with this design project. The rest of the paper will include (II) Research, (III) Hardware Design, (IV) Project Continuation, (V) Project Management, (VI) Ethical Concerns/Issues, (VII) Manufacture and Marketability

II. Research

Where to begin?

The initial step in our research was to understand the current optical density sensor Solix uses in its daily operations. We obtained a data sheet from the Optek website shown in figure 1.

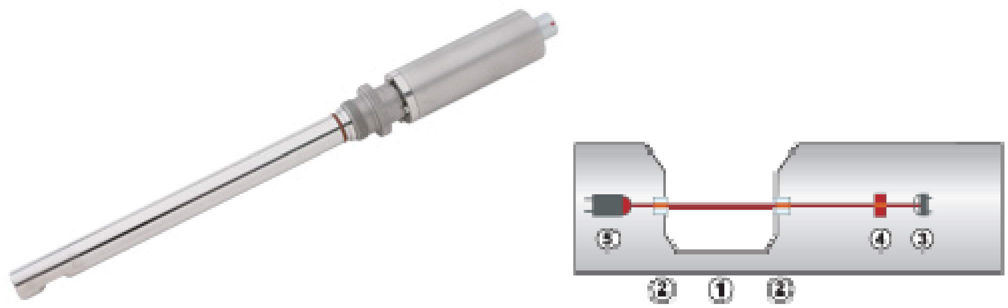


Fig. 1 Optek Sensor (www.optek.com)

Seen above is the basic design of the sensor. There is an infrared LED shown above as 5 which emits a light at 840nm to 910 nm wavelength. The light travels through a sapphire lens (2), then through the channel (1), then through another sapphire lens. This is to focus the light as it passes through the channel. The light then passes through a daylight filter (4), which filters out any other sources of light. Finally the light is captured by a detector (3), and then equated as a voltage. The probe is placed in the liquid that the cells are growing in channel side first. When the algae cells are small there is more room for the light to pass through the liquid in the channel, so the detector detects more light and emits a higher voltage. Therefore as the size of the cells increases the voltage output decreases. This process of light scattering is described by Lambert-Beer's Law which equates the size of a cell in a liquid with the transmission of light through it. The problems with this design were as stated before a high cost and that they foul easily.

Lambert-Beers's Law

$$T = \frac{I}{I_0} = 10^{-\alpha \ell} = 10^{-\varepsilon \ell c}$$

Fig. 2 Lambert-Beer's Law
(see Appendix A for abbreviations)

LED Light Source

The first component investigated was the LED light source. The Optek sensor uses NIR light because it is insensitive to color changes. The Solix biology team provided a range of wave lengths of light that are sensitive to chlorophyll. This is shown in figure 4. This figure shows the relationship between absorbance of light by chlorophyll at different wavelengths of light. It is plain to see that between 697 – 865 nm wavelengths that there

is no absorption of light due to chlorophyll. This means that this would be the perfect range of wavelengths to measure the size of the cells only.

The Solix biology team also has a sensor that measures the optical density of algae. This device operates at 750 nm wavelength. This originally made a target wavelength of 750 nm for the sensor.

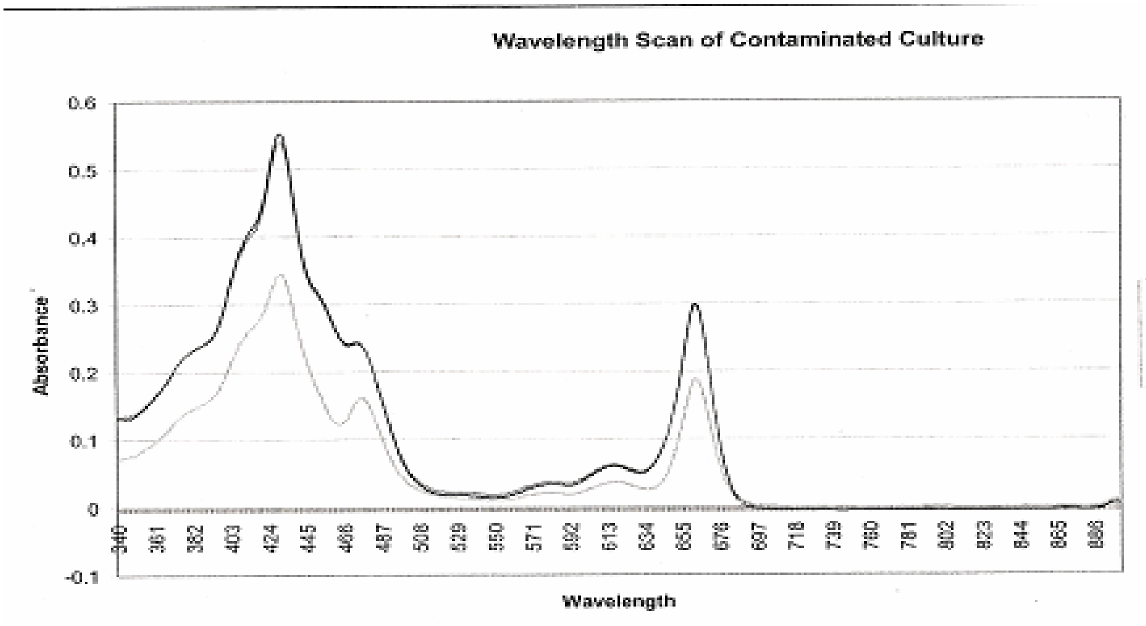


Fig. 3 Absorbance of Chlorophyll vs. Wavelength

Sapphire Lenses

The next area a research was to examine the use of sapphire lenses. Sapphire is often chosen as an optical substrate when the application requires high mechanical durability and high thermal conductivity, as well as good transmission between UV, Visible, and IR regions.

Daylight Filter

The next area of research was to examine the daylight filters. This prevents outside sources of light from having an effect on your output. This is important since the readings will all be made outside. A daylight filter is also known as a neutral density filter. A neutral density filter is a "grey" filter. An ideal neutral density filter reduces light of all wavelengths or colors equally. Practical neutral density filters are not perfect as they do not reduce the intensity of all wavelengths equally. They are only specified over the visible region of the spectrum, and do not proportionally block all wavelengths of ultraviolet or infrared radiation.

Detector

The finally area of research was the detector. There are two basic premises behind turning light into current or voltage, the photodiode and phototransistor. The photodiode is a diode that is forward biased when a light from a band of wavelengths reaches the P substrate. This bandwidth is determined by the material used to construct the P substrate. A phototransistor is a transistor that is biased when a bandwidth of light crosses the gate of the transistor. This bandwidth is also affected by the materials used. Although these detectors will usually pass a number of wavelengths, they all have a peak wavelength where they operate optimally.

III. Hardware Design

A. Prototype 1

Design

The purpose of prototype 1 was to build and play with a circuit that measured light. This circuit was not of our own design but one we researched and found online. The idea was to learn from this circuit, that it may give us ideas on how to go about designing our own circuit. The circuit we built was found online at www.educypedia.be/electronics/circuitssensorslight.html. The circuit is shown in figure 4.

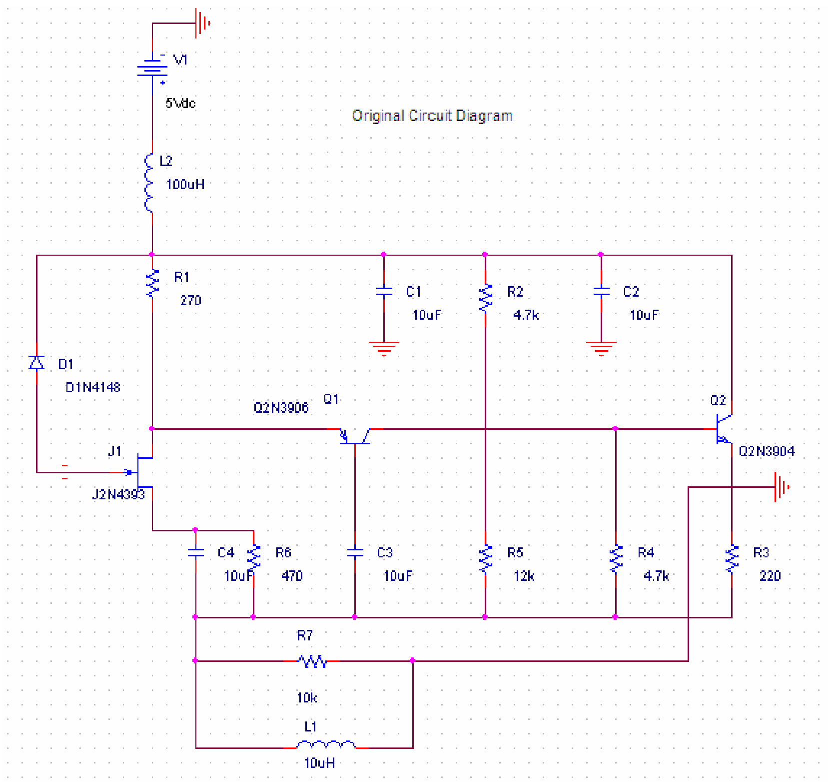


Fig. 4 Circuit 1

This circuit was built not to be a design used on our project, but rather to give us an idea of how a basic optoelectric circuit behaves. The circuit contains a Motorola MRD500 photodiode that detects light from .3 micrometers to 1.1 micrometers in wavelength.

Testing Procedure

The purpose of this circuit was to detect daylight and not light in the NIR spectra. This circuit was used to see how different light sources affected the output. This was preformed with various experiments. The first experiment measured the output voltage in direct sunlight as opposed to indoors. The next experiment involved shining a light at the photodiode to obtain an increase in voltage across R3. The finally experiment involved isolating the circuit from any outside sources to see zero output voltage across R3.

Results

The experiment showed no difference in output voltage when the circuit was moved from inside to outside. When all outside light is taken away the output voltage was zero. The experiment did show good steady state output when we placed an LED in line with the photodiode.

B. Prototype 2

Design

The second design was created to try and emulate the circuit in the Optek sensor and to have the circuit operate in the NIR range. Circuit shown in figure 5.

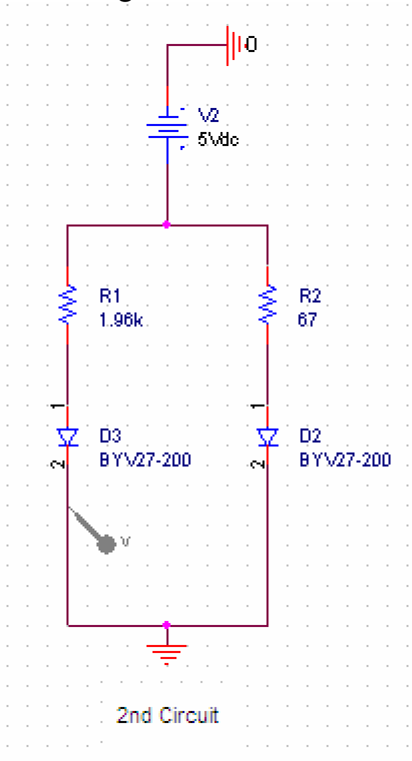


Fig 5 Circuit 2

The parts for the second prototype were sourced from a company, Texas Advanced Optoelectronic Solutions (TAOS), that made optical sensors. For this design implemented their TSL260R which is a Silicon IC containing a photodiode, operation amplifier, and feedback components. This device operated in a range form 850nm to 1000nm wavelength with its highest irradiance responsivity at 940nm. This was paired this with a NTE3029 LED that operates at 940nm. The theory behind this circuit was that as the light across the phototransistor increases the current through R2 increases and therefore the voltage increases. So as the density of the algae solution increases the voltage should decrease.

Testing Procedure 1

In order to test this circuit, two cuvettes were filled with solutions of algae of different densities including, a cuvette with tap water and another with no liquid at all. Using the circuit as shown above measurements were taken of the voltage across R2 for each of the cuvettes. This is shown in figure 6.

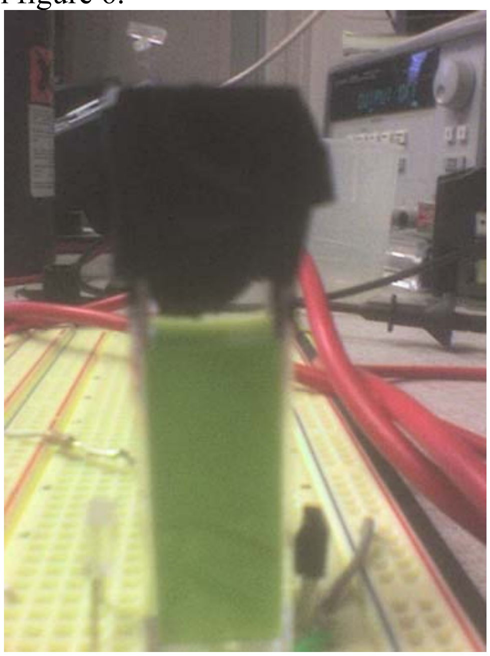


Fig 6 Testing a Cuvette

Results and Conclusions 1

This experiment did not provide expected results. There was no d drop in voltage across R2 for any of the cuvettes. The only way to obtain a voltage drop was to have solid object between the emitter and receiver. The conclusion was that the intensity of the LED was too high and decided to retest with different LED and phototransistor pairs.

Testing Procedure 2

The second experiment involved gradually increasing the resistance of R1 until there was a voltage drop for the algae solution. The first procedure was then repeated.

Results and Conclusions 2

The resistance of R1 was increased to 9.66 kilo ohms. The results are shown in table 1.

Substance	Output 1 (V)	Output 2 (V)	Output 3 (V)
Air	.586	.575	.590
Water	.573	.566	.562
Algae (less dense)	.250	.122	.301
Algae (more dense)	.360	.485	.444

Table 1 Results for Prototype 2

These experiments did show a difference in output for various substances but concluded that this circuit would not meet our goals. The difference in output voltages was on the order of millivolts and the goal was to see a difference between a 0-5 volt range. The larger problem however was the output of the circuit was unstable. There was no repeatability in reproducing the same results for any parameters in this experiment. After further research it was determined that the irradiance level for this LED was too high for the phototransistor being used. By decreasing the current through the LED there was in turn a decrease in the irradiance of the device; however this created an operating range outside of the peak range of performance for the diode thereby causing instability in the output.

C. Prototype 3

Design

The goal of this design was to implement a 750 nm LED into our previous design using another device from TAOS that operated within this wavelength. It was not possible to obtain a 750 nm LED that we could obtain in quantities less than 2000 at a time. The next available wavelength LED operated with an output wavelength of 850 nm from SunLED (XTHI12W850). This LED was paired with an NPN phototransistor from SunLED (XTHI12W850), which operates with a high responsivity at 850nm.

Testing Procedure

The circuit was initially tested on a breadboard similarly to our previous experiments. The first experiment used three different densities of algae with a control of pure water. Cuvettes were filled with the substances and used to test the variation of output voltages per density of material.

Results and Conclusions

The recorded results are shown in table 2.

Substance	Out put 1 (V)	Out put 2 (V)
Water	3.46	3.455
Algea (low density)	1.459	1.455
Algea (medium density)	1.172	1.256
Algea (high density)	0.805	0.724

Table 2 Results for Prototype 3

The conclusion was that the results were acceptable for this circuit design. The differences in output voltage for each experiment were due to the instability of the components position due to being in a breadboard.

Testing Device

Two different designs for testing the new components were created to try and stabilize our circuit. The first design was not very stable and had to be redesigned. The second design is shown in figure 7.

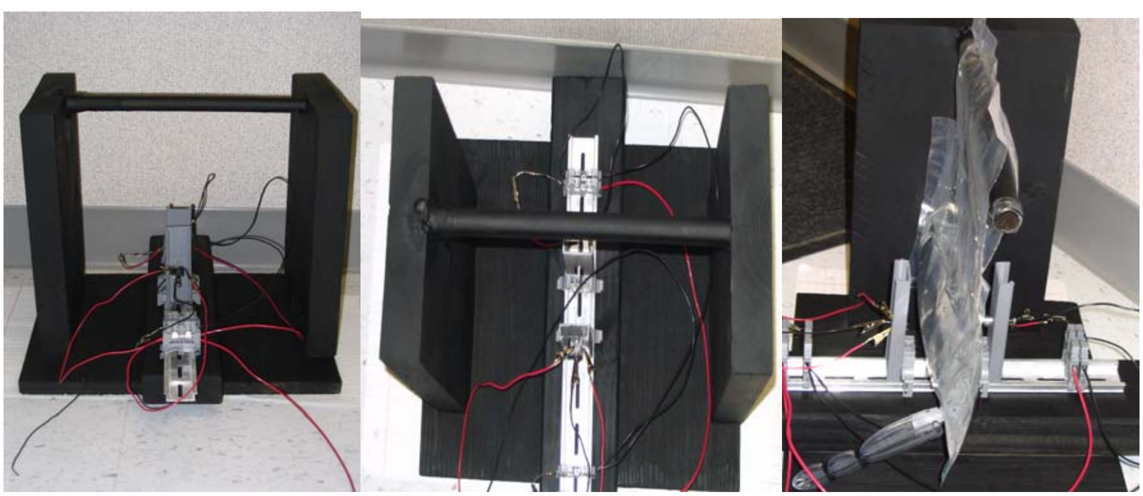


FIG 7 Prototype 3

This design was ideal because it secured the electronic components of the circuit and also simulated a similar environment in which the final design would be used. This design is also flexible in the movements of the diodes and transistors which allow testing with different bags and materials.

D. Prototype 4

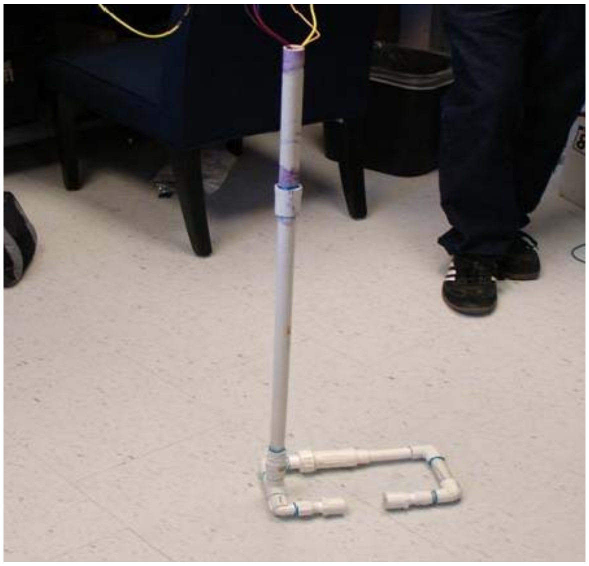


FIG 8 Prototype 4

Design

This prototype was designed to begin to testing underwater in the actual environment that the device would be used. This had to be a watertight model. It was constructed out of PVC piping with an adjustable arm to find an acceptable distance between the emitter and the receiver. The encasement contained the same hardware used in prototype 3. The emitter consisted of the 850 nm LED from SunLED (XTHI12W850) and the receiver, its matched NPN phototransistor from SunLED (XRNI82B). The LED and phototransistor were placed behind two pieces of glass. Later, neutral density filters would be placed on the transistor side to filter out day light. These filters blocked out light in the visible spectrum and allowed the light in the NIR range to pass through. Below is a graph of wavelength vs. transmission.

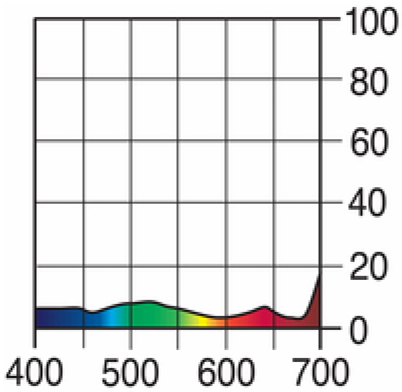


FIG 9 Neutral Density Filter Graph

http://www.leefiltersusa.com/lighting/products/comparator/keywords:299/page:1/act:result/ref:C4630710C94918/changeTab:getcolor

Testing Procedure

These were the first tests the team was able to do on the actual bags, outside and underwater. The sensor was placed with the emitter and the receiver on both sides of the bag and a FLUKE multi-meter was used to measure the change in voltage across the different densities of algae. With these tests the distance between the emitter and receiver were adjusted to find optimum distance. The results of these experiments showed an optimum distance at approximately 4 cm or less between the emitter and receiver.

Results and Conclusions

The Results received can be seen in table 3

Bag Number	Output 1 (V)	Output 2 (V)	Output (G/L) *Solix provided
Initial reading	4.98	4.89	-
4A	3.78	3.66	.889
4B	3.1	3.05	2.889
3A	3.57	3.6	1.64

Table 3 results for prototype 4

Looking at the data it appears to be inconsistent to what was originally expected. After considerable testing it was determined that outside light was affecting the output of the sensor. Neutral density filters were added on the phototransistor side of the sensor to block out light in the visible spectrum (see Figure $$).

E. Prototype 5

Figure 10 Prototype 5

Design
Using the data from prototype 4 the final prototype was constructed. Prototype 5 was constructed out of galvanized steel to give it a more ridged design. The transmitter and the emitter were placed at fixed distances from each other. See figures below.

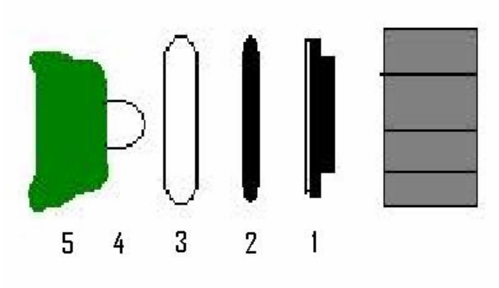


FIG 11 Transmiting Side
(1)Plastic mounting, (2) O-ring, (3)Glass lense, (4) 850 nm LED, (5) Foam Mounting

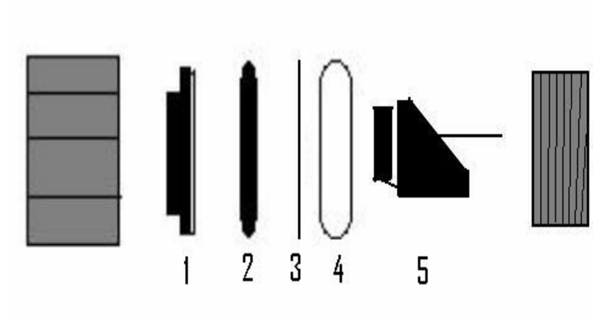


FIG 12 Receiving Side
(1) Plastic mounting, (2) O-ring, (3) Neutral density filter, (4) Glass lense, (5) Phototransistor with mount

The output of the phototransistor goes to an LF412 op amp set up as a voltage follower. The ouput signal of the op amp goes to the L41005P process meter. The process meter allows the user to program a nonlinear curve based on the voltages from the sensor. This creates a correlation between dry mass of algae (G/L) and voltage of the sensor.

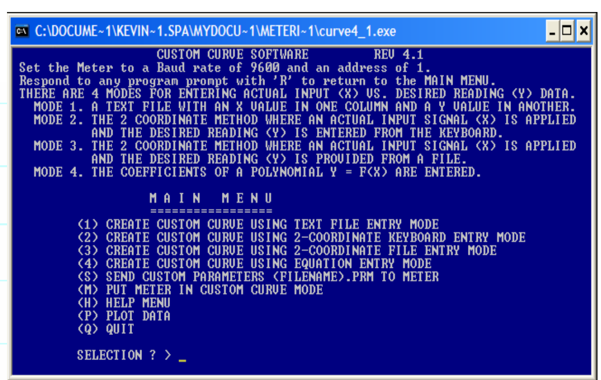


FIG 13 Process Meter

FIG 14 Process Meter Software

This protoype is also completely powered by batteries. And the final addition to the prototype was a moveable shield to block sunlight.

Data Capture

Using sensor and the process meter data points were captured. Using known dry mass samples from Solix's biology team a table was created relating known dry mass (G/L) to the output voltages of the sensor. The data points were programmed into the process meter's software using visual basic code. This created an output on the front display of the process meter that displays the dry mass of the algae (G/L) as a function of the voltage at the output of the sensor. See the graph below.

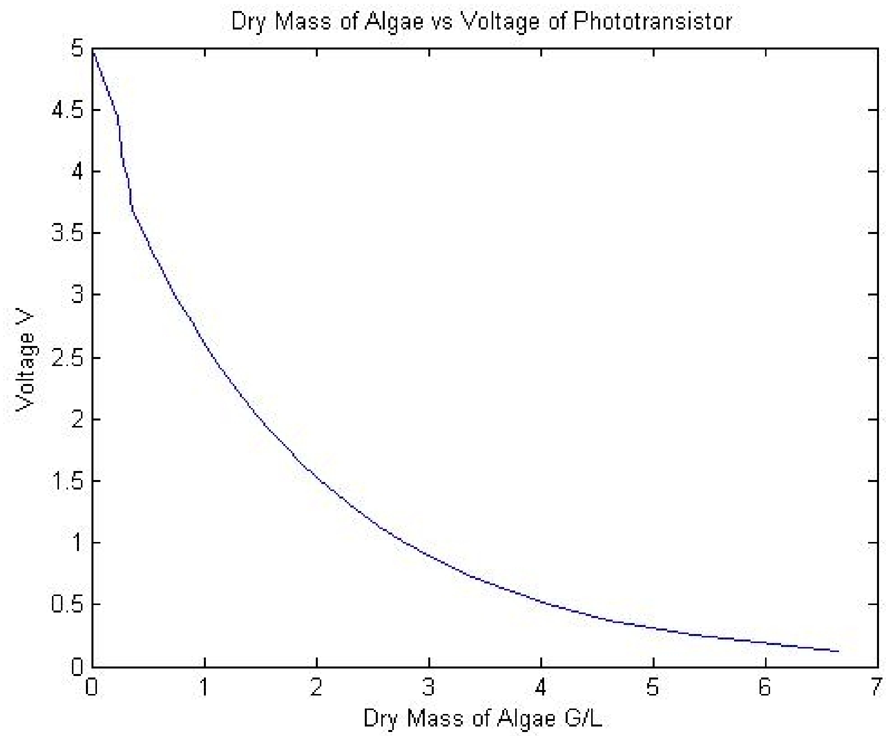


FIG 15

With the final curve in place tests were then performed multiple times on multiple days to test the accuracy and repeatability of the sensor with known dry mass samples of algae.

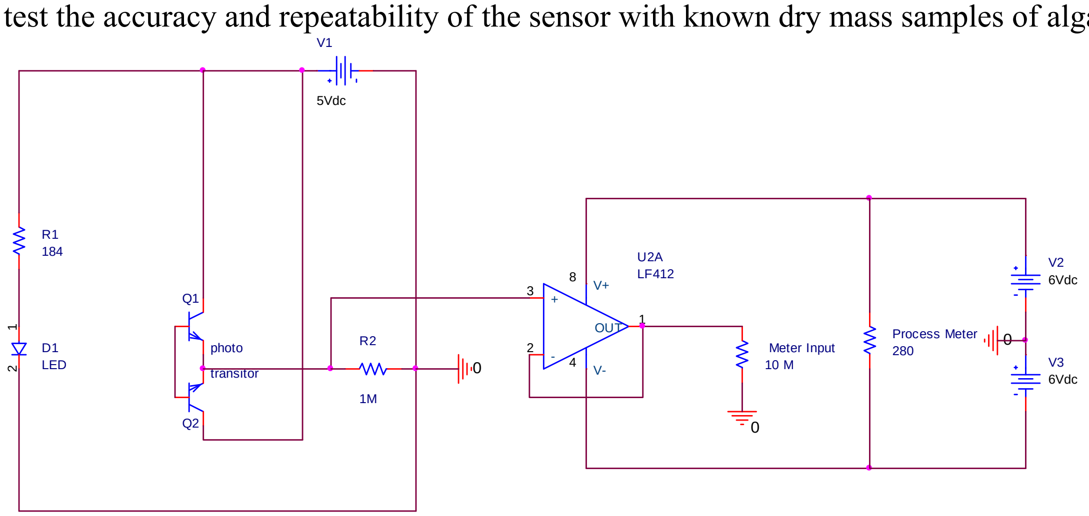


FIG 16 Prototype 5 Circuit

<u>IV. Project Continuation</u>

When the project with Solix Biofuels was started, we were given the task to redesign a more affordable density sensor to measure the biomass of algae. We were successful at taking the project from concept to a completed prototype measuring device. It is possible that Solix has a use for our sensor and if so there are some possibilities for a continuation of work. If a group were to continue this project some recommended objectives include:

- More circuit analyses
- Advanced light filtering technique
- Further testing and calibration
- Different packaging of the final product.

<u>More circuit analyses</u>

A group could take a look at the circuitry work we have done with the voltage follower as well as the basic structure of the LED and phototransistor. There is room for more advanced circuitry work to allot for more accurate data.

<u>Advanced light filtering technique</u>

The sensor currently has neutral density filters at work to try and eliminate much of the light in the visible spectrum. It seems to be effective but there is still some light getting read into the phototransistor. A group could look into a more precise way to eliminate the remainder of the excess light similar to that used by the Optek sensor.

<u>Further testing and calibration</u>

The current prototype could go through further testing in the field. It could be tested primarily for consistency as well as accuracy in the data by comparing data to that of the biologist team at Solix. Upon receiving more data it would be possible to further the accuracy of the curve being used by the digital panel meter to increase the accuracy of the meter.

<u>Different packaging of the final product</u>

This portion would best fit as a mechanical engineering project because it would require a new design of the final packaged product. Perhaps one made out of a lighter material while maintain the same rigidity that was the product of the galvanized steel. It could also take the form of a one handed device.

V. Project Management

Semester 1

Initially our project revolved around research. Since we have no optics experience we decided as a team to try and research as much about optics as possible. Once we had a basic understanding we would then split the research three ways and report our finding weekly. All experimentation with different circuits was done as a team so we would all have capable knowledge of the subject.

Semester 2

Since we had all ready come up with our basic design our main goals were to build a working prototype and improve the existing circuit. Due to our unique skill sets we decided to split these tasks into three parts to more effectively accomplish these goals. Jeremiah Young was in charge of parts acquisition and to assist the team in tasks as needed. These tasks included setting up the processor, data collection and administrative tasks. Kevin Spahr was in charge of researching and testing of possible ways to improve upon the current circuit design. Rob Haslinger was in charge of building and testing a working prototype, as well as the maintenance of the project website. In order to accomplish these goals we came up with the following timetable.

Week	Rob	Kevin	Jeremiah
1/21	Project goals. Update website	Test bags for uniform consistency.	Acquire parts. Help as needed.
1/28	Work on prototype.	Test density. Improve circuit.	Acquire parts. Help as needed
2/4	Work on prototype.	Improve circuit.	Acquire parts. Help as needed
2/11	Work on prototype.	Improve circuit.	Acquire parts. Help as needed
2/18	Finish prototype.	Improve circuit.	Acquire parts. Help as needed

2/25	Test prototype. Adjust prototype.	Improve circuit.	Acquire parts. Help as needed
3/04	Test prototype. Adjust prototype.	Improve circuit.	Acquire parts. Help as needed
3/11	Test prototype. Adjust prototype.	Improve circuit.	Acquire parts. Help as needed
3/18	Test prototype. Adjust prototype.	Improve circuit.	Acquire panel meter.
3/25	Test prototype. Adjust prototype.	Improve circuit.	Acquire panel meter.
4/1	Test prototype. Adjust prototype.	Finalize design. Test design.	Set up panel meter.
4/8	Finalize Prototype	Finalize Prototype	Set up panel meter
4/15	Finalize Prototype. E-Days	Finalize Prototype. E-Days	Finalize panel meter E-Days
4/22	Finalize Testing.	Finalize Testing.	Finalize Testing.
4/29	Finalize Testing.	Finalize Testing.	Adjust panel meter
5/6	Finalize Testing.	Finalize Testing.	Finalize Testing

Table 4 Spring 09 Timeline

VI. Manufacture and Marketability

The current design of our product was designed to be a practical solution to a specific problem. The design was conceived with the current system being used at Solix Biofuels in mind. Since the sensor relies on the design of the algae reactors at Solix, the manufacturability and marketability are also linked directly to the success of Solix and the system used.

Marketability

Solix Biofuels is a company currently focused on the development and commercialization of large-scale algae-to-biofuels system. Its intellectual property is in reactor technology, controls, biology, and downstream processing. Since our design was created for their reactors the marketability of our product depends on their success. Our product could either be sold directly through Solix or through a referral system from Solix to their clients. The total cost to manufacture this product would be $433.02 plus the cost of labor. This of course would change with a machined body.

Part	Cost
LF-412CN OP AMP	1.67
Round LED mount	1.25
PCH 150 phototransistor mount	0.80
phototransistor	1.05
850nm LED	0.60
1 MΩ resistor	0.20
180 Ω resistor	0.06
Copper wire (25 ft)	1.60
Glass Lenses (2)	4.00
Circuit board	4.00
Chassis box	34.72
Lens mounting structure (2)	4.00
Conduit (2)	5.94
Galvanized steel elbows (4)	7.28
Galvanized steel 'T' junction	1.57
Galvanized steel rods (7)	9.03
Neutral density filter	1.00
Plexiglas	2.00
Digital panel meter	350.00
O-Ring (2)	0.25
Handle	2.00
Total	$433.02

Table 5 Cost Breakdown

Manufacturability

Our current design was made by hand and then calibrated based upon its reaction to different conditions in the environment. Due to the limited number of these sensors that would be needed it would not make since to mass produce the sensor. Each sensor would need to be hand produced and then calibrated for accuracy. The casing for the sensor was built out of materials available and team members' mechanical experience. A machined part specifically designed to hold our circuitry would be preferable for accuracy as well as dependability. If these parts were available this product could be easily hand manufactured by hand in the limited quantity needed.

Bibliography

Hobbs, Philip C.D. Building Electro-Optical Systems: Making It All Work. New York: Wiley-Interscience Publication, 2000.

Johnson, David. "High Speed Light Detector." Light Detector Width FET 2000. Educypedia. September 14th 2008. <www.educypedia.be/electronics/circuitssensorslight.htm >

Nunley, William and Bechtel, J. Scott. Infrared Optoelectronics: Devices And Applications. New York: Marcel Dekker, 1987.

Seippel, Robert G. Optoelectronics. Virginia: Reston, 1981.

Appendix A – Abbreviations

IR - infrared
NIR – near infrared
UV – ultraviolet
LED – light emitting diode
nm- nano-meters
T – transmission
α - absorption coefficient
ℓ - path length
ε - molar absorptivity
I_0 ,I - intensity

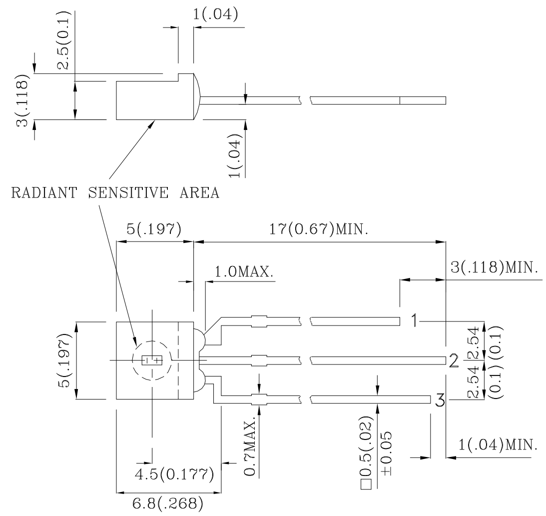
Appendix B

Date	Part	Supplier	Quantity	Price	Deposits	Remaining Budget
8/25/08	New Semester Funds	CSU			$150.00	$ 150.00
9/10/08	Photodiode	NTE	3	$0.99	$ -	$ 147.03
	Photodiode	NTE	3	$0.99	$ -	$ 144.06
	Infrared Emitter	NTE	2	$1.55	$ -	$ 140.96
9/24/08	10 *10^ -6 Farad Capacitor	NTE	6	$1.00	$ -	$ 134.96
	100 *10^ -6 Henry Inductor	NTE	2	$1.80	$ -	$ 131.36
	10 *10^ -6 Henry Inductor	NTE	2	$3.99	$ -	$ 123.38
	MOSFET	NTE	2	$2.09	$ -	$ 119.20
	BJT	NTE	2	$1.19	$ -	$ 116.82
	BJT	NTE	2	$1.55	$ -	$ 113.72
	TAOS Infrared-Photodiode	TAOS	3	$0.00	$ -	$ 113.72
10/15/08	430nm LED	SunLED	2	$0.00	$ -	$ 113.72
	468nm LED	SunLED	2	$0.00	$ -	$ 113.72
	555nm LED	SunLED	2	$0.00	$ -	$ 113.72
	590nm LED	SunLED	2	$0.00	$ -	$ 113.72
	627nm LED	SunLED	2	$0.00	$ -	$ 113.72
	650nm LED	SunLED	2	$0.00	$ -	$ 113.72
	660nm LED	SunLED	2	$0.00	$ -	$ 113.72
	700nm LED	SunLED	2	$0.00	$ -	$ 113.72
10/29/08	700nm LED	SunLED	2	$0.00	$ -	$ 113.72
	850nm LED	SunLED	2	$0.00	$ -	$ 113.72
	880nm LED	SunLED	2	$0.00	$ -	$ 113.72
	NIR Photodiode	SunLED	3	$0.00	$ -	$ 113.72
	400-640nm photodiode	TAOS	3	$0.00	$ -	$ 113.72
1/20/09	New Semester Funds	CSU			$150.00	$ 263.72
1/21/09	PVC parts	Home Depot	4	$2.33	$ -	$ 261.39
2/4/09	PVC parts	Home Depot	3	$8.57	$ -	$ 252.82
3/3/09	MOSFET	NTE	2	$10.49	$ -	$ 230.43
3/25/09	Digital Panel Meter	Laurel Electronics	1	$350.00	$ -	$ -119.57
3/26/09	Neutral Density Filter	Lights On	1	$17.55	$ -	$ -137.12
3/31/09	Steel Piping	Home Depot	5	$10.09	$ -	$ -147.21
4/1/09	Poster Board	Wal-Mart	1	$9.44	$ -	$ -156.65
	Wet Foam	Wal-Mart	1	$3.48	$ -	$ -160.13
	Steel Piping and parts	Home Depot	12	$19.08	$ -	$ -179.21
4/9/09	Conduit	Home Depot	1	$5.94	$ -	$ -185.15
	Components	Home Depot	1	$1.46	$ -	$ -186.61
4/10/09	Chassis Box	Mountain States	1	$37.05	$ -	$ -223.66
4/11/09	Handle	Home Depot	1	$3.19	$ -	$ -226.85
4/16/09	Batteries		1	$11.20	$ -	$ -238.05
	Glue		1	$2.96	$ -	$ -241.01
4/30/09		Solix			$241.01	$ 0.00

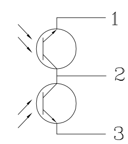
Appendix C – Data Sheets

Features

- MECHANICALLY AND SPECTRALLY MATCHED TO THE INFRARED EMITTING LED LAMP SERIES.
- BLACK DIFFUSED LENS.
- COUPLED WITH INFRARED EMITTING LED LAMP SERIES FOR MOUSE APPLICATION.
- RoHS COMPLIANT.



1 EMITTER (PTR A)
2 COLLECTOR (COM)
3 EMITTER (PTR B)



Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ± 0.25(0.01") unless otherwise noted.
3. Specifications are subject to change without notice.

Absolute Maximum Ratings at TA=25°C

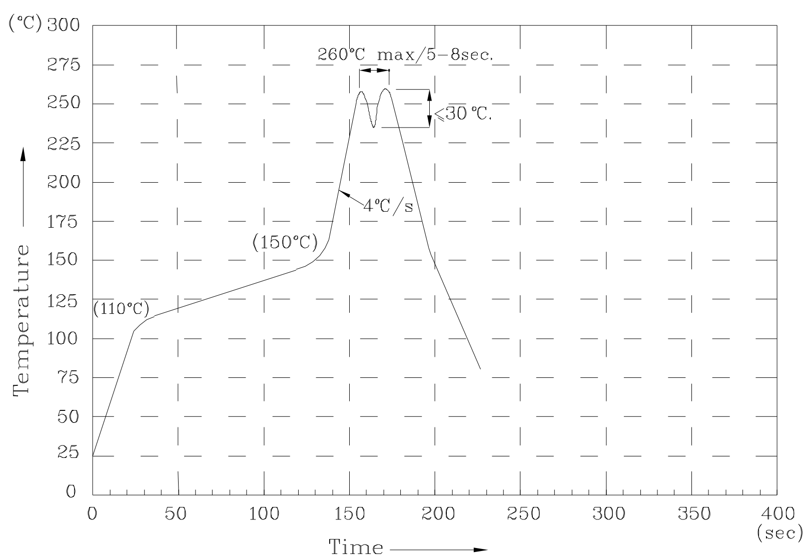
Parameter	Max. Ratings
Collector-to-Emitter Voltage	30V
Emitter-to-Collector Voltage	5V
Power Dissipation at (or below) 25°C Free Air Temperature	100mW
Operating / Storage Temperature Range	-55°C To +100°C
Lead Soldering Temperature (>5mm for 5sec)	260°C

Electrical / Optical Characteristics at T_A=25°C

Symbol	Parameter	Min.	Typ.	Max.	Unit	Test Condition
$V_{BR\ CEO}$	Collector-to-Emitter Breakdown Voltage	30	-	-	V	I_C=100 μ A Ee=0mW/cm²
$V_{BR\ ECO}$	Emitter-to-Collector Breakdown Voltage	5	-	-	V	I_E=100 μ A Ee=0mW/cm²
$V_{CE(SAT)}$	Collector-to-Emitter Saturation Voltage	-	-	0.4	V	I_C=500 μ A Ee=5mW/cm²
I_{CEO}	Collector Dark Current	-	-	100	nA	V_{CE}=10V Ee=0mW/cm²
T_R	Rise Time (10% to 90%)	-	16	-	μ s	V_{CE}=5V I_C=1mA R_L=1K Ω
T_F	Fall Time (90% to 10%)	-	18	-	μ s	
$I_{(ON)}$	On State Collector Current	0.1	0.4	-	mA	V_{CE}=5V Ee=1mW/cm2 λ=940nm
R	Collector Current Ratio of Phototransistor	0.8	1	1.25	Ω	Ic (on) (a)/ Ic(on) (b)

XRNI82B

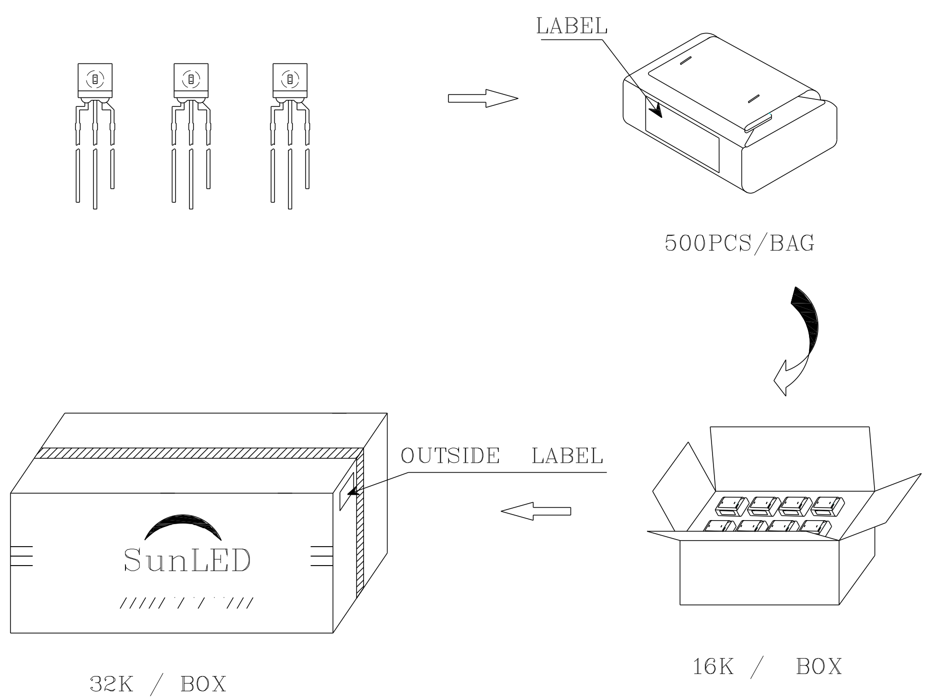
Wave Soldering Profile For Lead-free Through-hole LED.

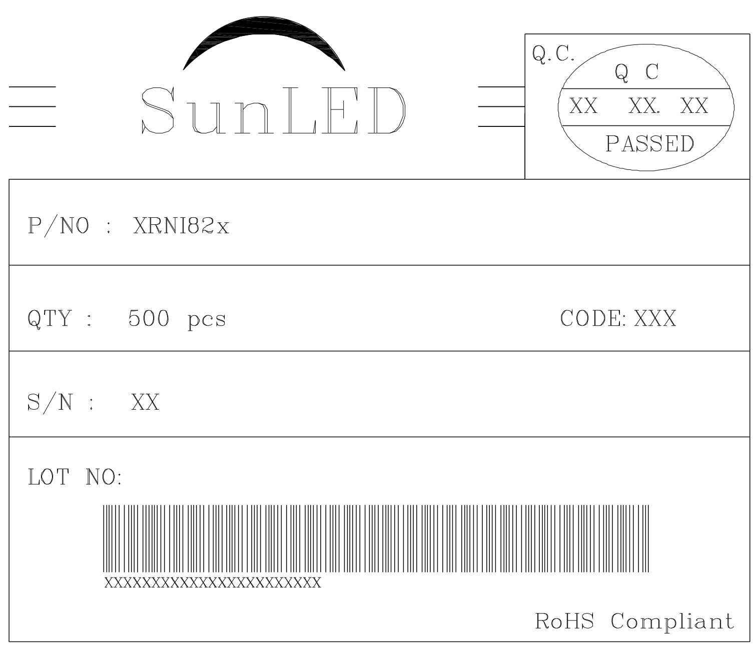


NOTES:

1. Recommend the wave temperature 245°C~260°C.The maximum soldering temperature should be less than 260°C.
2. Do not apply stress on epoxy resins when temperature is over 85 degree°C.
3. The soldering profile apply to the lead free soldering (Sn/Cu/Ag alloy).
4. No more than once.

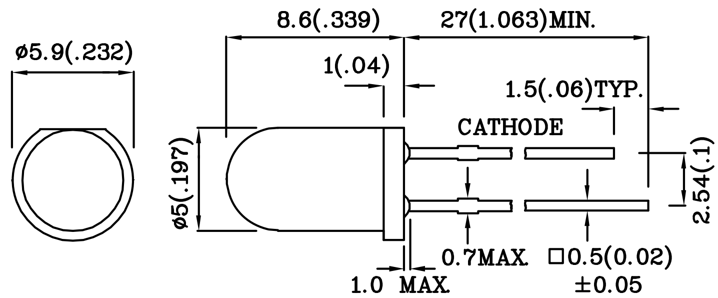
PACKING & LABEL SPECIFICATIONS XRNI82B





Features

- MECHANICALLY AND SPECTRALLY MATCHED TO THE PHOTOTRANSISTOR.
- WATER CLEAR LENS.
- RoHS COMPLIANT.

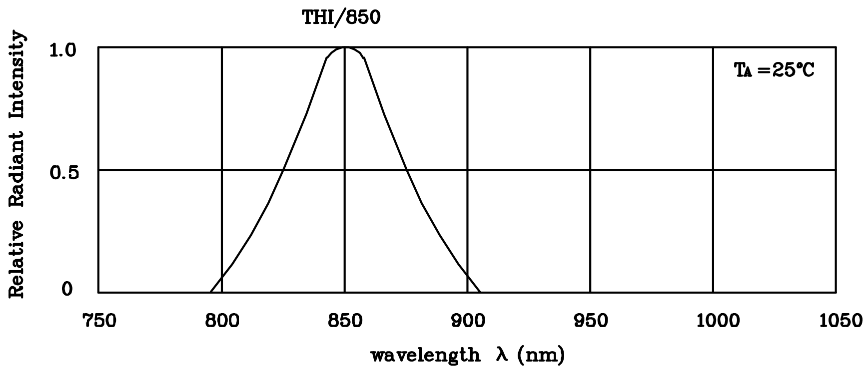


Notes:
1. All dimensions are in millimeters (inches).
2. Tolerance is ± 0.25(0.01") unless otherwise noted.
3.Specifications are subject to change without notice.

Absolute Maximum Ratings (T_A=25°C)		**THI/850 (GaAlAs)**	**Unit**
Reverse Voltage	V_R	5	V
Forward Current	I_F	50	mA
Forward Current (Peak) 1/100 Duty Cycle 10us Pulse Width	i_{FS}	1	A
Power Dissipation	P_T	80	mW
Operating Temperature	T_A	-40 ~ +85	°C
Storage Temperature	Tstg	-40 ~ +85	
Lead Solder Temperature [2mm Below Package Base]	260°C For 3 Seconds		
Lead Solder Temperature [5mm Below Package Base]	260°C For 5 Seconds		

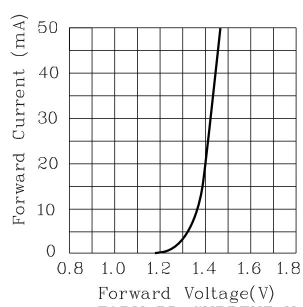
Operating Characteristics (T_A=25°C)		**THI/850 (GaAlAs)**	**Unit**
Forward Voltage (Typ.) (I_F=20mA)	V_F	1.4	V
Forward Voltage (Max.) (I_F=20mA)	V_F	1.6	V
Reverse Current (Max.) (V_R=5V)	I_R	10	uA
Wavelength Of Peak Emission (Typ.) (I_F=20mA)	λ P	850	nm
Spectral Line Full Width At Half-Maximum (Typ.) (I_F=20mA)	Δλ	50	nm
Capacitance (Typ.) (V_F=0V, f=1MHz)	C	30	pF

Part Number	Emitting Material	Lens-color	Luminous Intensity (Po=Mw/sr) @20mA *50mA		Wavelength nm λ P	Viewing Angle 2 θ 1/2
			min.	typ.		
XTHI12W850	GaAlAs	Water Clear	10	39	850	20°
			*50	*98		

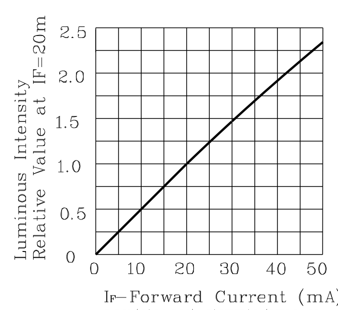


RELATIVE INTENSITY Vs. WAVELENGTH

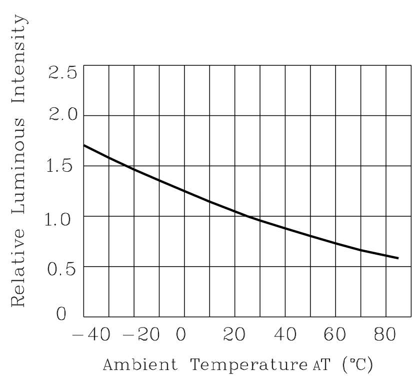
❖ **THI/850**



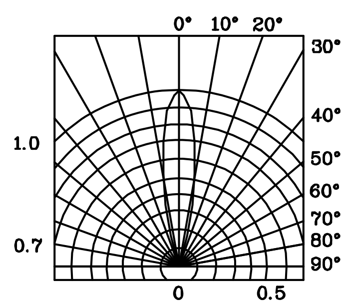
FORWARD CURRENT Vs.
FORWARD VOLTAGE



LUMINOUS INTENSITY Vs.
FORWARD CURRENT

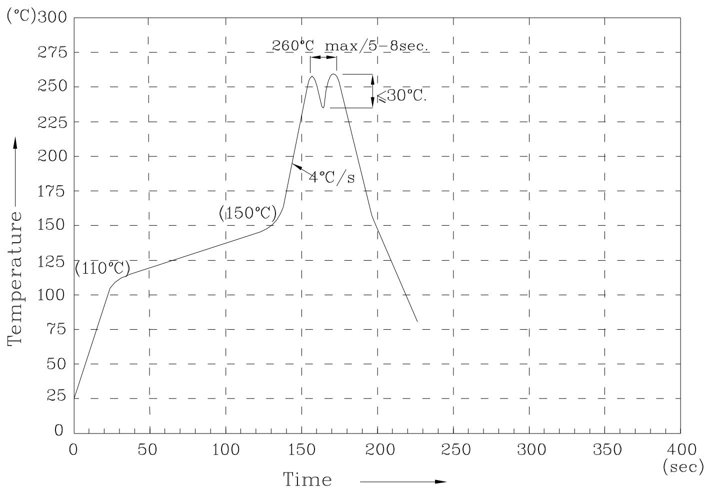


LUMINOUS INTENSITY Vs.
AMBIENT TEMPERATURE



SPATIAL DISTRIBUTION

Wave Soldering Profile For Lead-free Through-hole LED.



NOTES:

1. Recommend the wave temperature 245°C~260°C. The maximum soldering temperature should be less than 260°C.
2. Do not apply stress on epoxy resins when temperature is over 85 degree°C.
3. The soldering profile apply to the lead free soldering (Sn/Cu/Ag alloy).
4. No more than once.

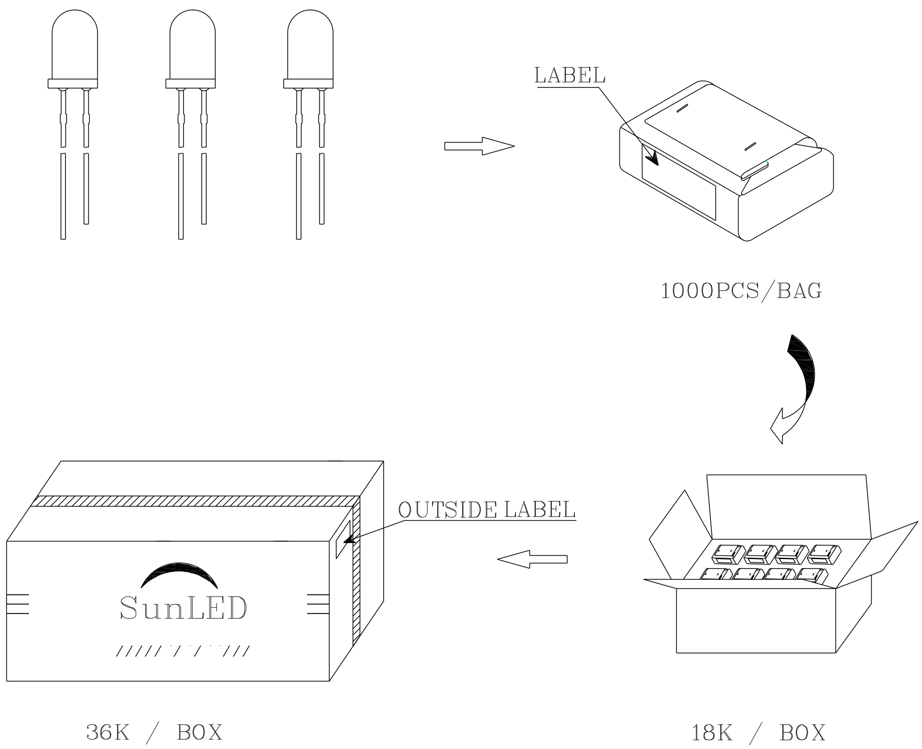
Remarks:

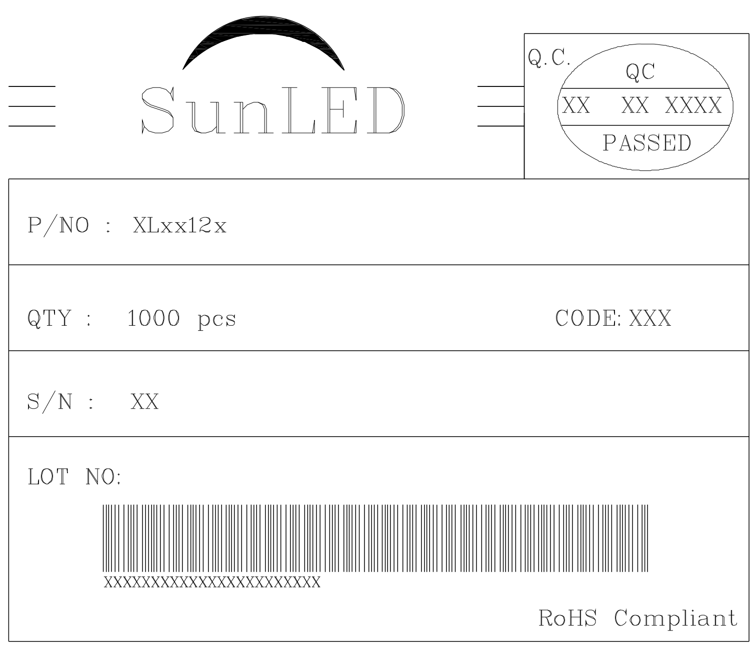
If special sorting is required (e.g. binning based on forward voltage or radiant intensity / luminous flux), the typical accuracy of the sorting process is as follows:

1. Radiant Intensity / Luminous Flux: +/-15%
2. Forward Voltage: +/-0.1V

Note: Accuracy may depend on the sorting parameters

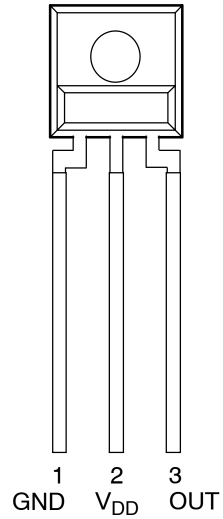
PACKING & LABEL SPECIFICATIONS **XTHI12W850**



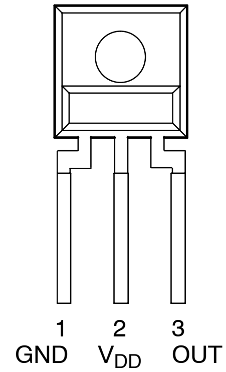


- **Integral Visible Light Cutoff Filter**
- **Monolithic Silicon IC Containing Photodiode, Operational Amplifier, and Feedback Components**
- **Converts Light Intensity to a Voltage**
- **High Irradiance Responsivity, Typically 111 mV/(μW/cm^2) at λ_p = 940 nm (TSL260R)**
- **Compact 3-Lead Plastic Package**
- **Single Voltage Supply Operation**
- **Low Dark (Offset) Voltage....10mV Max**
- **Low Supply Current......1.1 mA Typical**
- **Wide Supply-Voltage Range.... 2.7 V to 5.5 V**
- **Replacements for TSL260, TSL261, and TSL262**
- **RoHS Compliant (−LF Package Only)**

PACKAGE S
SIDELOOKER
(FRONT VIEW)



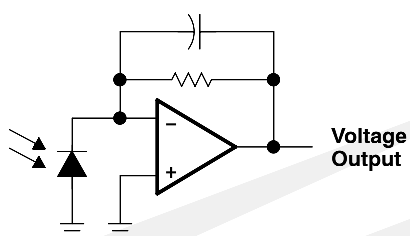
PACKAGE SM
SURFACE MOUNT
SIDELOOKER
(FRONT VIEW)



Description

The TSL260R, TSL261R, and TSL262R are infrared light-to-voltage optical sensors, each combining a photodiode and a transimpedance amplifier (feedback resistor = 16 MΩ, 8 MΩ, and 2.8 MΩ respectively) on a single monolithic IC. Output voltage is directly proportional to the light intensity (irradiance) on the photodiode. These devices have improved amplifier offset-voltage stability and low power consumption and are supplied in a 3-lead plastic sidelooker package with an integral visible light cutoff filter and lens. When supplied in the lead (Pb) free package, the device is RoHS compliant.

Functional Block Diagram



Available Options

DEVICE	T_A	PACKAGE − LEADS	PACKAGE DESIGNATOR	ORDERING NUMBER
TSL260R	0°C to 70°C	3-lead Sidelooker	S	TSL260R
TSL260R	0°C to 70°C	3-lead Sidelooker — Lead (Pb) Free	S	TSL260R−LF
TSL260R	0°C to 70°C	3-lead Surface-Mount Sidelooker — Lead (Pb) Free	SM	TSL260RSM−LF
TSL261R	0°C to 70°C	3-lead Sidelooker	S	TSL261R
TSL261R	0°C to 70°C	3-lead Sidelooker — Lead (Pb) Free	S	TSL261R−LF
TSL261R	0°C to 70°C	3-lead Surface-Mount Sidelooker — Lead (Pb) Free	SM	TSL261RSM−LF
TSL262R	0°C to 70°C	3-lead Sidelooker	S	TSL262R
TSL262R	0°C to 70°C	3-lead Sidelooker — Lead (Pb) Free	S	TSL262R−LF
TSL262R	0°C to 70°C	3-lead Surface-Mount Sidelooker — Lead (Pb) Free	SM	TSL262RSM−LF

Texas Advanced Optoelectronic Solutions Inc.
1001 Klein Road • Suite 300 • Plano, TX 75074 • (972) 673-0759
www.taosinc.com

Terminal Functions

TERMINAL NAME	TERMINAL NO.	DESCRIPTION
GND	1	Ground (substrate). All voltages are referenced to GND.
OUT	3	Output voltage
V_{DD}	2	Supply voltage

Absolute Maximum Ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage, V_{DD} (see Note 1) . . . . 6 V
Output current, I_O . . . . ±10 mA
Duration of short-circuit current at (or below) 25°C (see Note 2) . . . . 5 s
Operating free-air temperature range, T_A . . . . −25°C to 85°C
Storage temperature range, T_{stg} . . . . −25°C to 85°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds (S Package) . . . . 260°C
Reflow solder, in accordance with J-STD-020C or J-STD-020D (SM Package) . . . . 260°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. All voltages are with respect to GND.
2. Output may be shorted to supply.

Recommended Operating Conditions

	MIN	NOM	MAX	UNIT
Supply voltage, V_{DD}	2.7		5.5	V
Operating free-air temperature, T_A	0		70	°C

Electrical Characteristics at V_{DD} = 5 V, T_A = 25°C, λp = 940 nm, R_L = 10 kΩ (unless otherwise noted) (see Notes 3, 4, and 5)

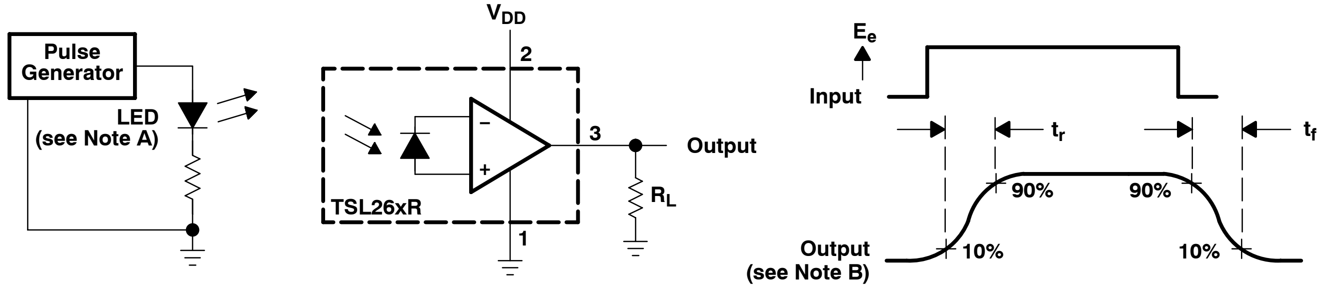
PARAMETER		TEST CONDITIONS	TSL260R			TSL261R			TSL262R			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
V_D	Dark voltage	E_e = 0	0	4	10	0	4	10	0	4	10	mV
V_{OM}	Maximum output voltage	V_{DD} = 4.5 V	3	3.3		3	3.3		3	3.3		V
V_O	Output voltage	E_e = 18 μW/cm²	1	2	3							V
		E_e = 46 μW/cm²				1	2	3				
		E_e = 220 μW/cm²							1	2	3	
α_{vo}	Temperature coefficient of output voltage (V_O)	E_e = 18 μW/cm², T_A = 0°C to 70°C		8								mV/°C
				0.4								%/°C
		E_e = 46 μW/cm², T_A = 0°C to 70°C					8					mV/°C
							0.4					%/°C
		E_e = 220 μW/cm², T_A = 0°C to 70°C								8		mV/°C
										0.4		%/°C
N_e	Irradiance responsivity	See Note 6		111			43.5			9.1		mV/(μW/cm²)
I_{DD}	Supply current	E_e = 18 μW/cm²		1.1	1.7							mA
		E_e = 46 μW/cm²					1.1	1.7				
		E_e = 220 μW/cm²								1.1	1.7	

NOTES: 3. Measurements are made with R_L = 10 kΩ between output and ground.
4. Optical measurements are made using small-angle incident radiation from an LED optical source.
5. The input irradiance E_e is supplied by a GaAs LED with peak wavelength λ_p = 940 nm
6. Irradiance responsivity is characterized over the range V_O = 0.05 to 2.9 V. The best-fit straight line of Output Voltage V_O versus irradiance E_e over this range will typically have a positive extrapolated V_O value for E_e = 0.

Dynamic Characteristics at T_A = 25°C (see Figure 1)

PARAMETER		TEST CONDITIONS	TSL260R			TSL261R			TSL262R			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
t_r	Output pulse rise time	V_{DD} = 5 V, λ_p = 940 nm		260			70			7		μs
t_f	Output pulse fall time	V_{DD} = 5 V, λ_p = 940 nm		260			70			7		μs
V_n	Output noise voltage	V_{DD} = 5 V, E_e = 0, f = 1000 Hz		0.8			0.7			0.6		μV/√Hz

PARAMETER MEASUREMENT INFORMATION



TEST CIRCUIT

VOLTAGE WAVEFORM

NOTES: A. The input irradiance is supplied by a pulsed GaAs light-emitting diode with the following characteristics: λ_p = 940 nm, t_r < 1 μs, t_f < 1 μs.

B. The output waveform is monitored on an oscilloscope with the following characteristics: t_r < 100 ns, $Z_i \geq$ 1 MΩ, $C_i \leq$ 20 pF.

Figure 1. Switching Times

TYPICAL CHARACTERISTICS

NORMALIZED OUTPUT VOLTAGE vs ANGULAR DISPLACEMENT

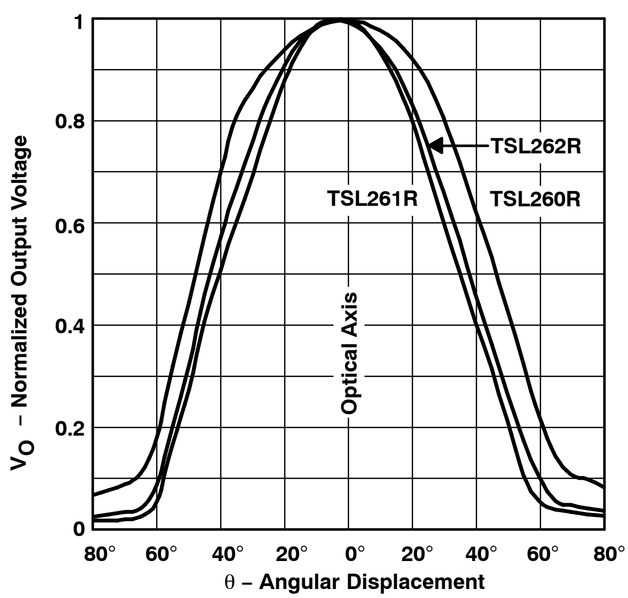


Figure 2

TYPICAL CHARACTERISTICS

OUTPUT VOLTAGE vs IRRADIANCE

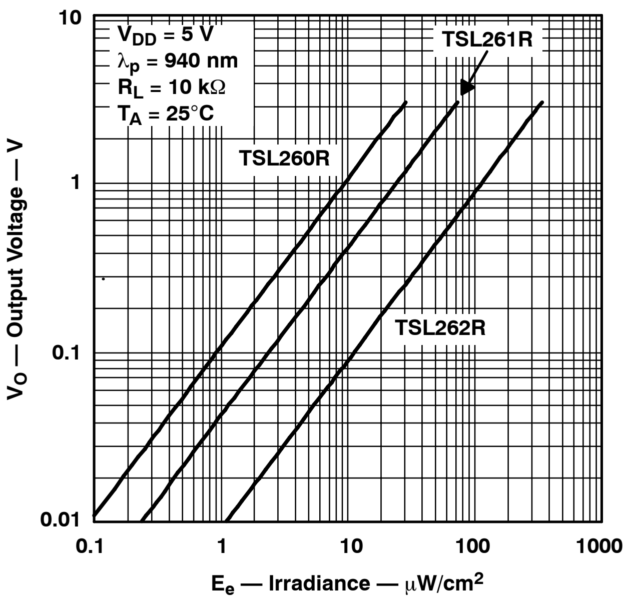


Figure 3

PHOTODIODE SPECTRAL RESPONSIVITY

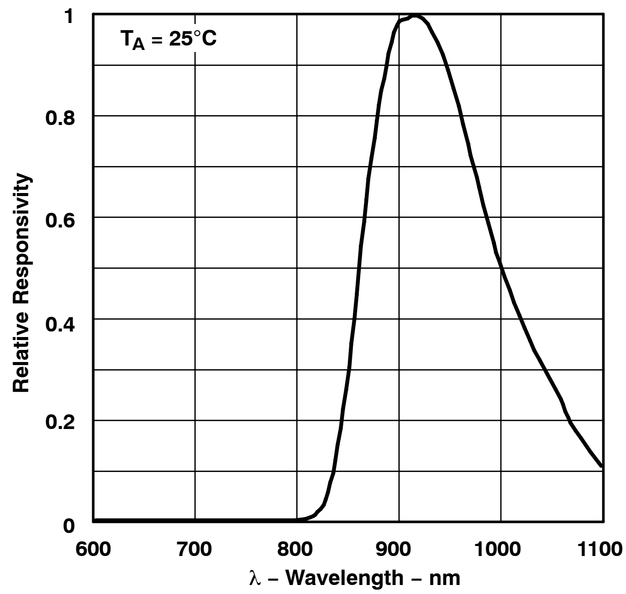


Figure 4

MAXIMUM OUTPUT VOLTAGE vs SUPPLY VOLTAGE

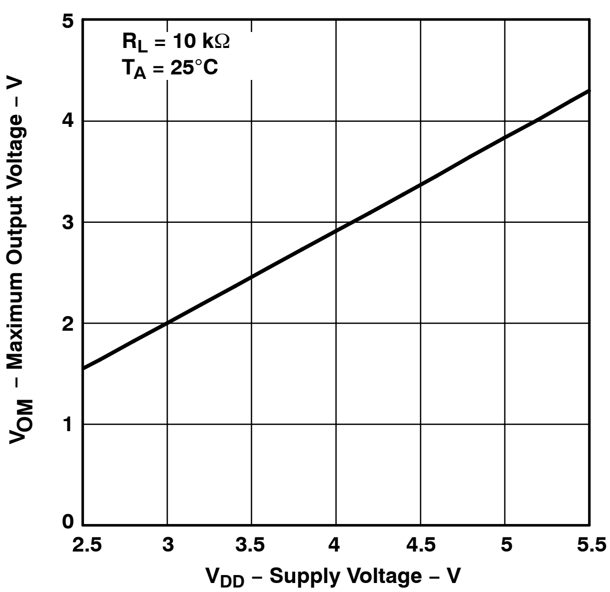


Figure 5

SUPPLY CURRENT vs OUTPUT VOLTAGE

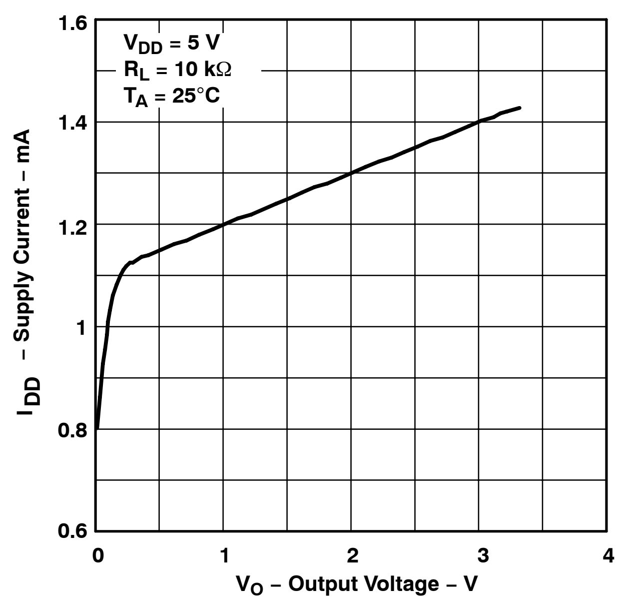
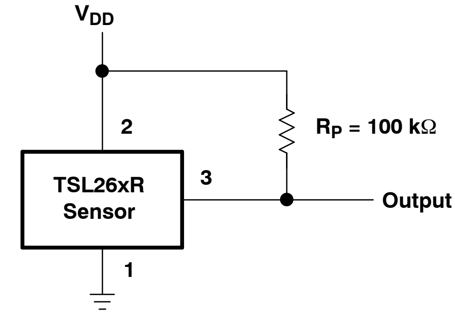


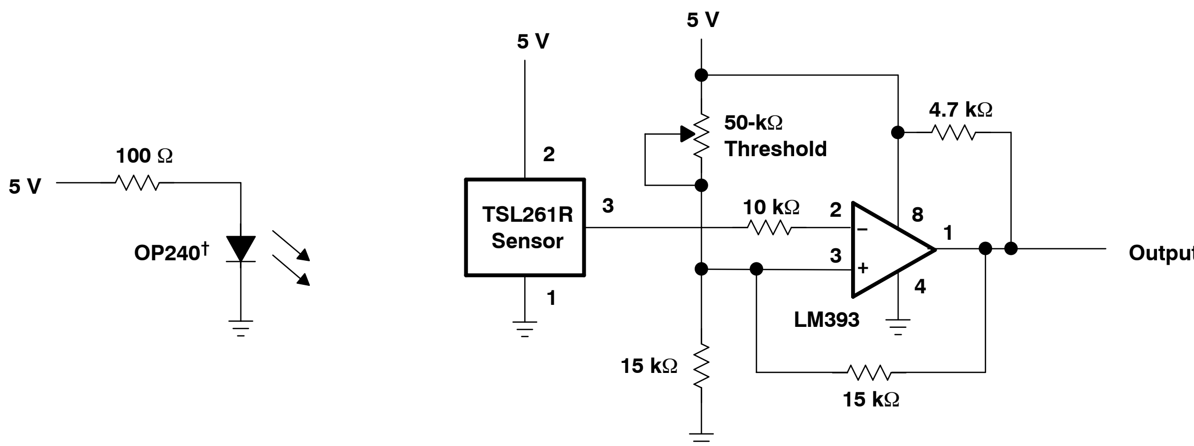
Figure 6

APPLICATION INFORMATION



NOTE A: Pullup resistor extends linear output range to near V_{DD} with minimal (several millivolts typical) effect on V_{DARK}; particularly useful at low V_{DD} (3 V to 5 V).

Figure 7. Pullup for Increased V_{OM}

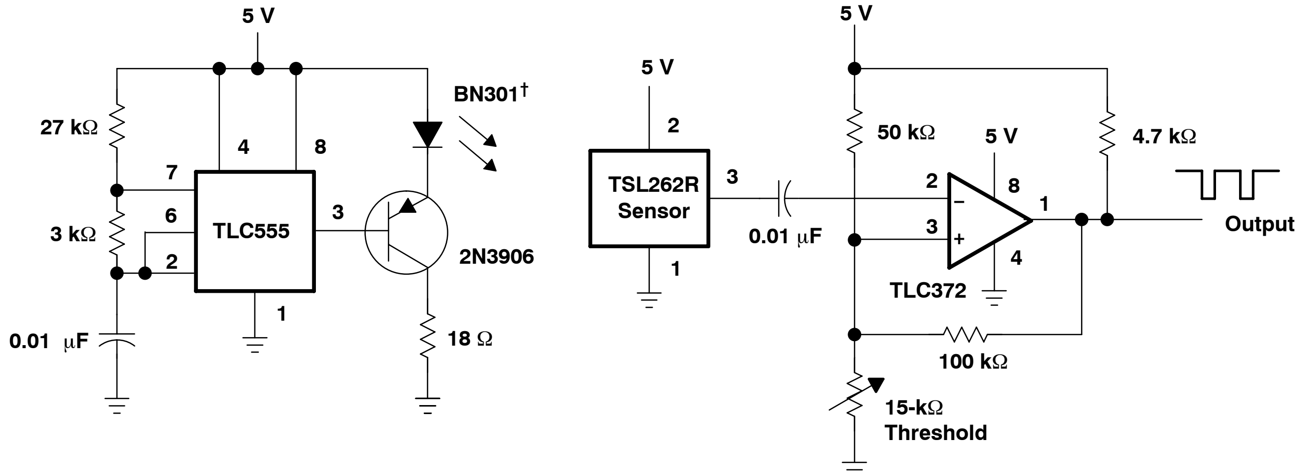


† OPTEK part number

NOTE A: Output goes high when beam is interrupted; working distance is several inches or less. Intended for use as optical-interrupter switch or reflective-object sensor.

Figure 8. Short-Range Optical Switch With Hysteresis

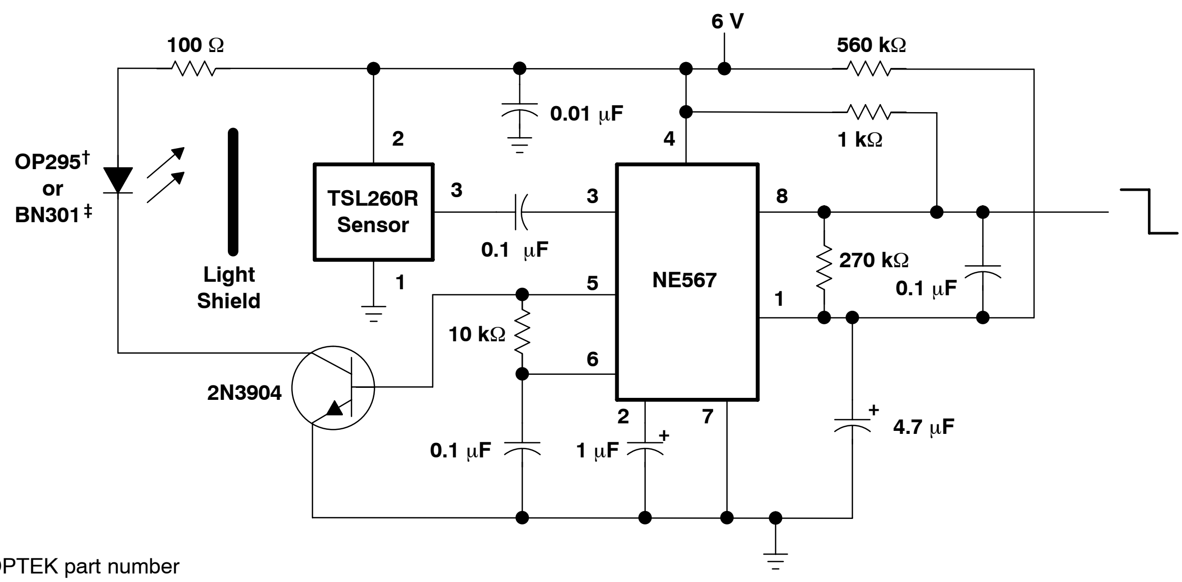
APPLICATION INFORMATION



† Stanley part number

NOTE A: Output pulses low until beam is interrupted. Useful range is 1 ft to 20 ft; can be extended with lenses. This configuration is suited for object detection, safety guards, security systems, and automatic doors.

Figure 9. Pulsed Optical-Beam Interrupter

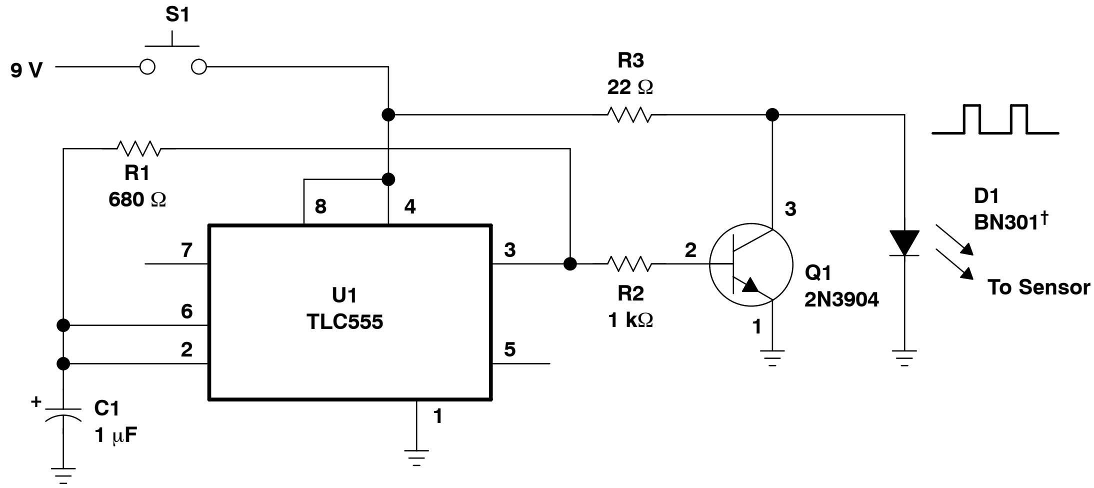


† OPTEK part number
‡ Stanley part number

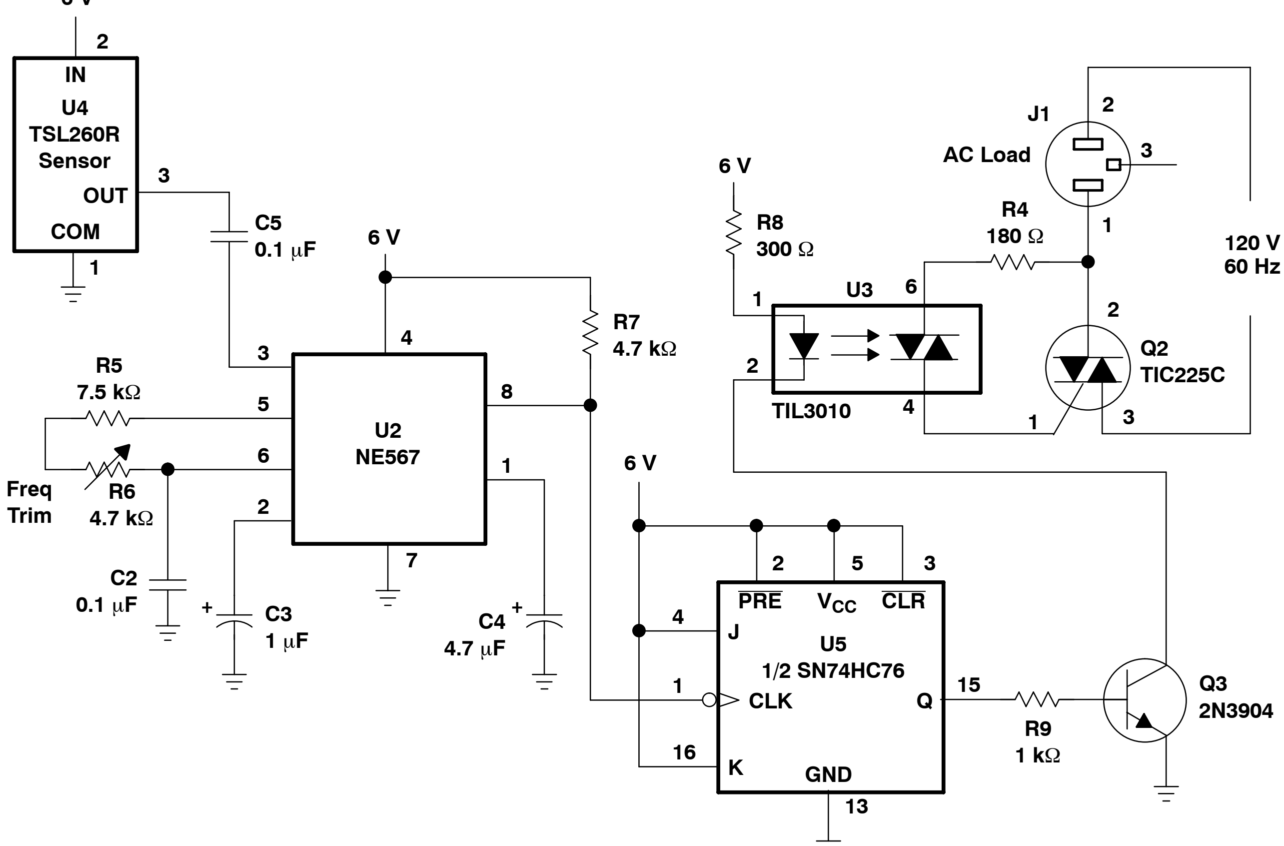
NOTE A: Output goes low when light pulses from emitter are reflected back to sensor. Range is 6 in to 18 in depending upon object reflectance. Useful for automatic doors, annunciators, object avoidance in robotics, automatic faucets, and security systems.

Figure 10. Proximity Detector

APPLICATION INFORMATION



TRANSMITTER



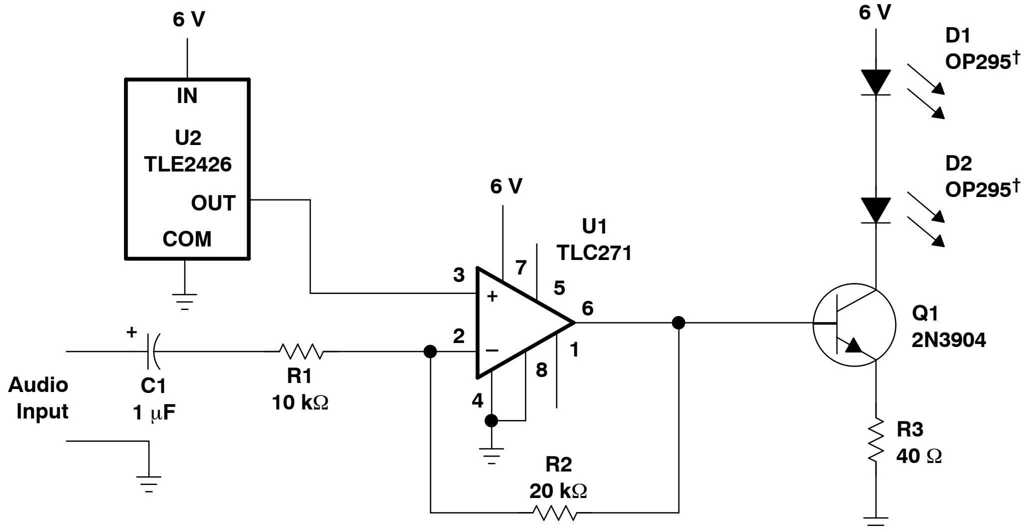
RECEIVER

† OPTEK part number

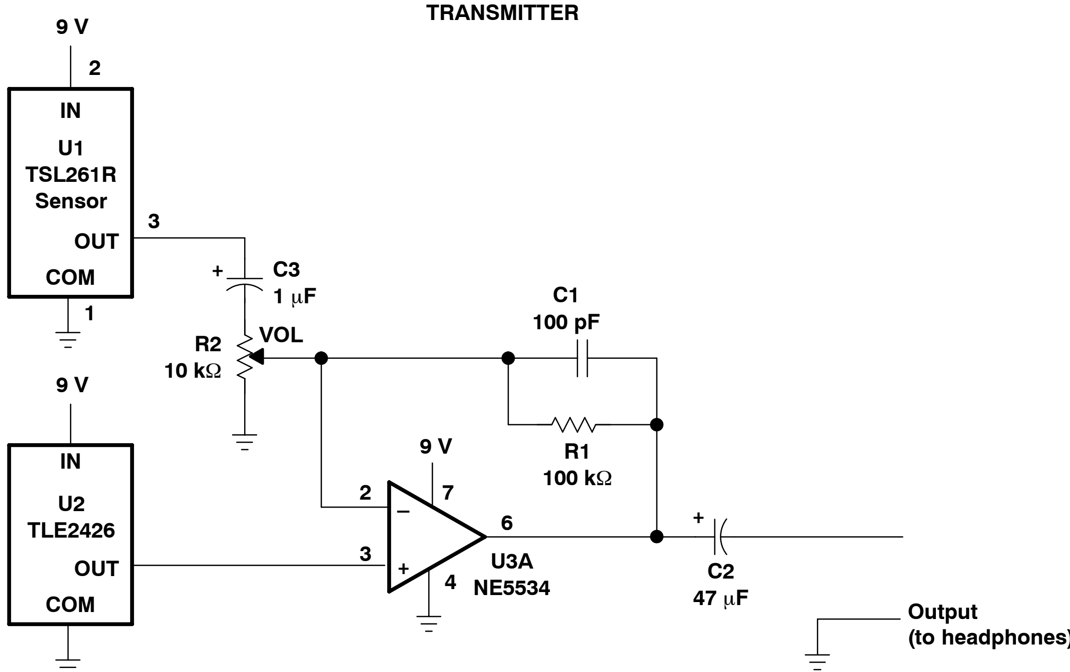
NOTE A: Single-channel remote control can be used to switch logic or light dc loads by way of U5 or ac loads by way of the optocoupler and triac as shown. Applications include ceiling fans, lamps, electric heaters, etc.

Figure 11. IR Remote Control

APPLICATION INFORMATION



TRANSMITTER



RECEIVER

† OPTEK part number

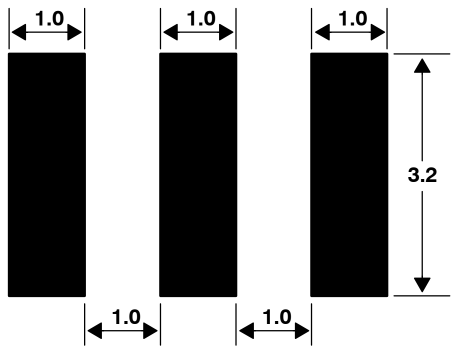
NOTE A: Simple transmission of audio signal over short distances (<10 ft). Applications include wireless headphones, wireless-telephone headset, and wireless-headset intercom.

Figure 12. IR Voice-Band Audio Link

APPLICATION INFORMATION

PCB Pad Layout

Suggested PCB pad layout guidelines for the SM surface mount package are shown in Figure 16.



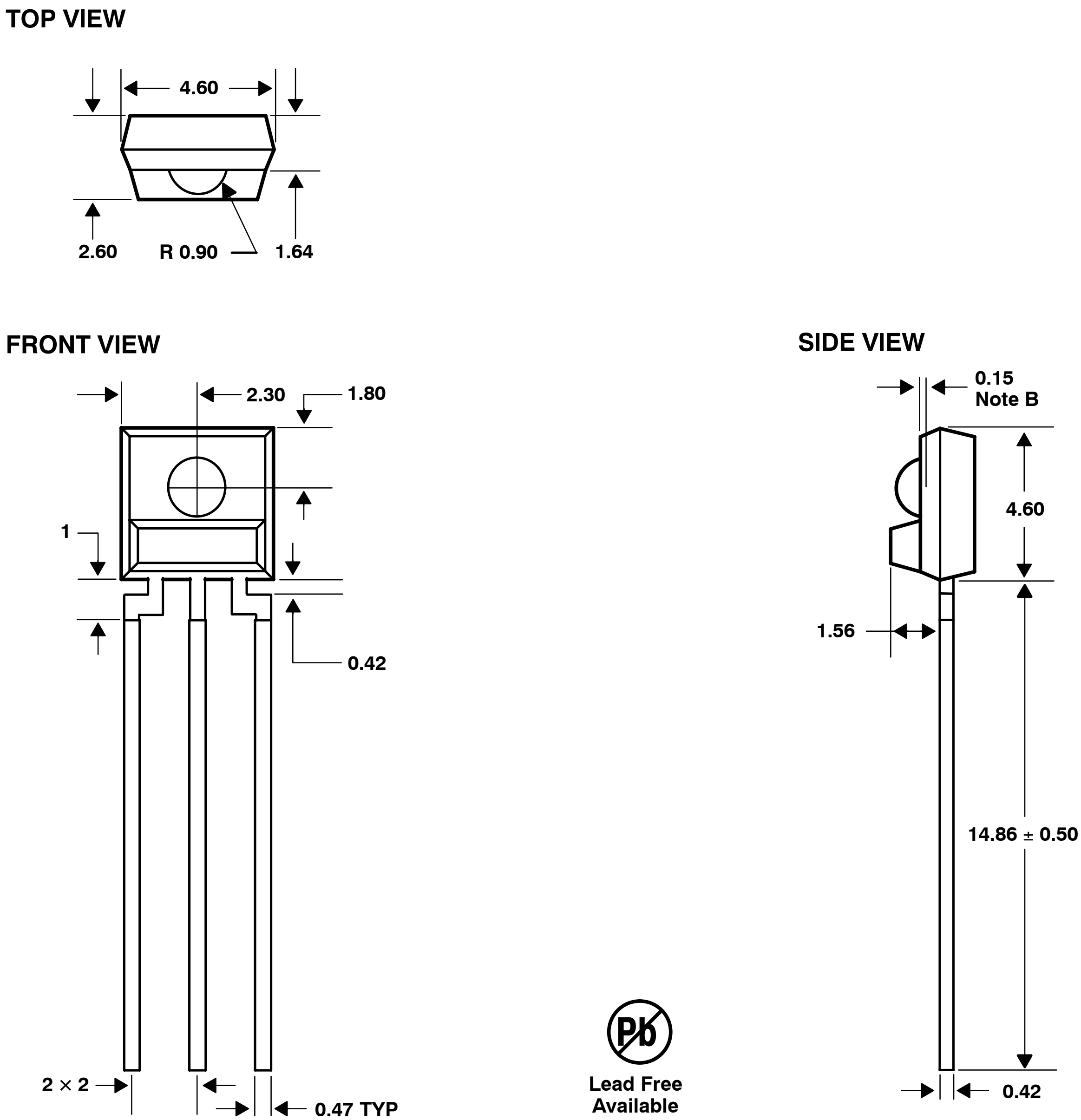
NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.

Figure 13. Suggested SM Package PCB Layout

MECHANICAL DATA

The TSL260R, TSL261R, and TSL262R are supplied in a clear 3-lead through-hole package with a molded lens. The integrated photodiode active area is typically 1,0 mm^2 (0.0016 in^2) for TSL260R, 0,5 mm^2 (0.00078 in^2) for the TSL261R, and 0,26 mm^2 (0.0004 in^2) for the TSL262R.

PACKAGE S **PLASTIC SINGLE-IN-LINE SIDE-LOOKER PACKAGE**



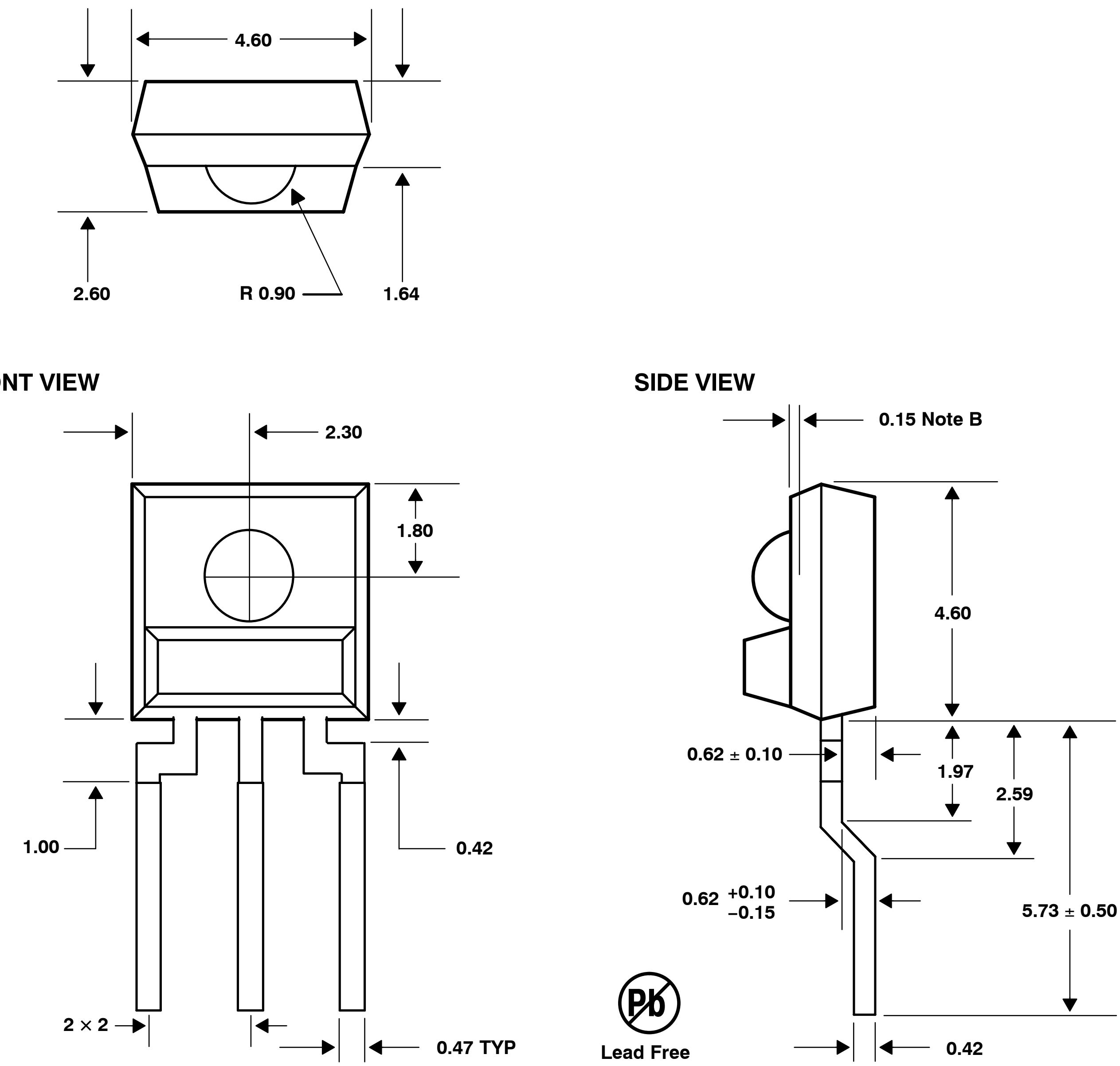
NOTES: A. All linear dimensions are in millimeters; tolerance is ± 0.25 mm unless otherwise stated.
B. Dimension is to center of lens arc, which is located below the package face.
C. The integrated photodiode active area is typically located in the center of the lens and 0.97 mm below the top of the lens surface.
D. Index of refraction of clear plastic is 1.55.
E. Lead finish for TSL26xR: solder dipped, 63% Sn/37% Pb. Lead finish for TSL26xR−LF: solder dipped, 100% Sn.
F. This drawing is subject to change without notice.

Figure 14. Package S — Single-In-Line Side-Looker Package Configuration

MECHANICAL DATA

PACKAGE SM **PLASTIC SURFACE MOUNT SIDE-LOOKER PACKAGE**

TOP VIEW



NOTES: A. All linear dimensions are in millimeters; tolerance is ± 0.25 mm unless otherwise stated.
B. Dimension is to center of lens arc, which is located below the package face.
C. The integrated photodiode active area is typically located in the center of the lens and 0.97 mm below the top of the lens surface.
D. Index of refraction of clear plastic is 1.55.
E. Lead finish for TSL26xRSM−LF: solder dipped, 100% Sn.
F. This drawing is subject to change without notice.

Figure 15. Package SM — Surface Mount Side-Looker Package Configuration

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National Semiconductor

August 2000

LF412
Low Offset, Low Drift Dual JFET Input Operational Amplifier

General Description

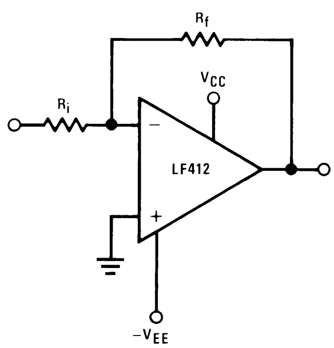
These devices are low cost, high speed, JFET input operational amplifiers with very low input offset voltage and guaranteed input offset voltage drift. They require low supply current yet maintain a large gain bandwidth product and fast slew rate. In addition, well matched high voltage JFET input devices provide very low input bias and offset currents. The LF412 dual is pin compatible with the LM1558, allowing designers to immediately upgrade the overall performance of existing designs.

These amplifiers may be used in applications such as high speed integrators, fast D/A converters, sample and hold circuits and many other circuits requiring low input offset voltage and drift, low input bias current, high input impedance, high slew rate and wide bandwidth.

Features

- Internally trimmed offset voltage: 1 mV (max)
- Input offset voltage drift: 10 μV/˚C (max)
- Low input bias current: 50 pA
- Low input noise current: $0.01\ pA/\sqrt{Hz}$
- Wide gain bandwidth: 3 MHz (min)
- High slew rate: 10V/μs (min)
- Low supply current: 1.8 mA/Amplifier
- High input impedance: $10^{12}\Omega$
- Low total harmonic distortion ≤0.02%
- Low 1/f noise corner: 50 Hz
- Fast settling time to 0.01%: 2 μs

Typical Connection



00565641

Ordering Information

LF412XYZ

X indicates electrical grade

Y indicates temperature range

"M" for military

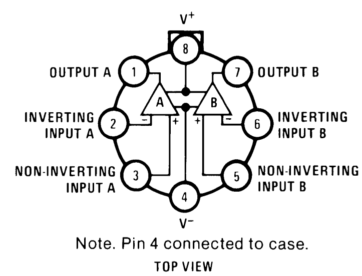
"C" for commercial

Z indicates package type

"H" or "N"

Connection Diagrams

Metal Can Package



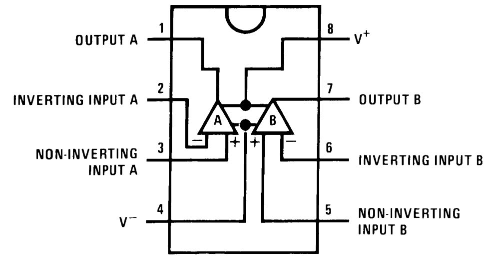
Note. Pin 4 connected to case.

TOP VIEW

00565642

Order Number LF412MH, LF412CH or LF412MH/883 (Note 1)
See NS Package Number H08A

Dual-In-Line Package



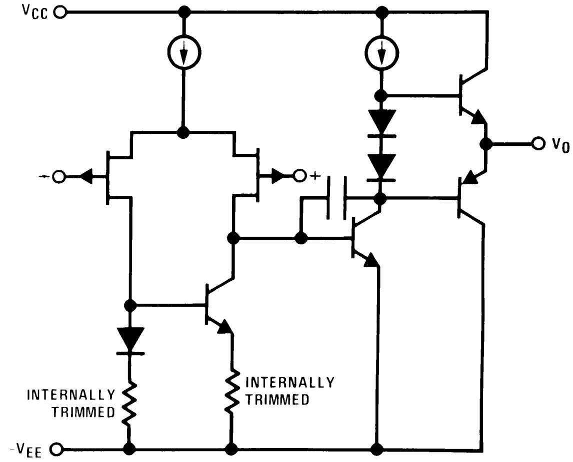
TOP VIEW

00565644

Order Number LF412ACN, LF412CN or LF412MJ/883 (Note 1)
See NS Package Number J08A or N08E

Simplified Schematic

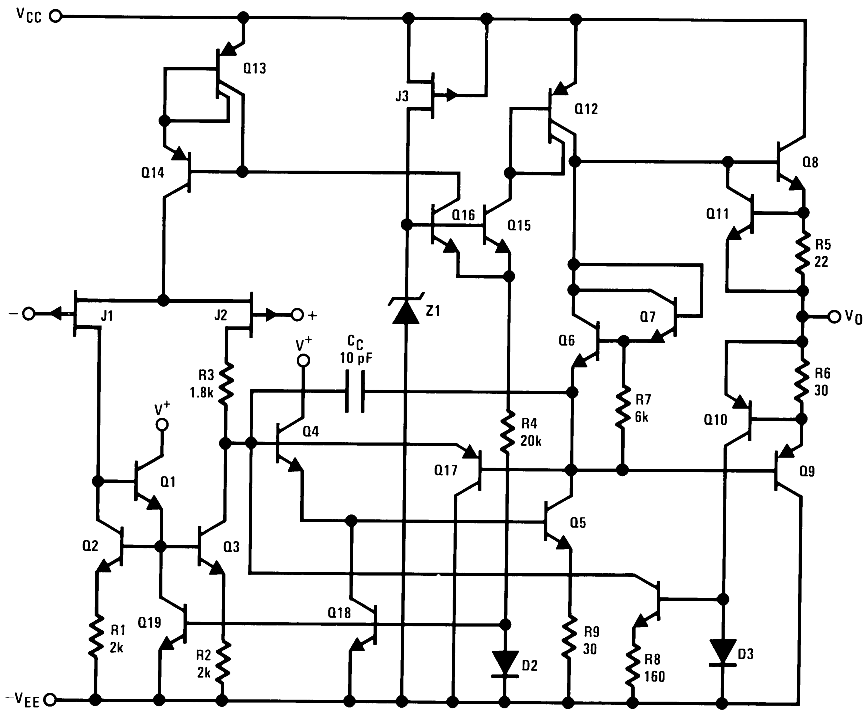
1/2 Dual



00565643

Note 1: Available per JM38510/11905

Detailed Schematic



00565632

Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

(Note 11)

	LF412A	LF412
Supply Voltage	±22V	±18V
Differential Input Voltage	±38V	±30V
Input voltage Range (Note 3)	±19V	±15V
Output Short Circuit Duration (Note 4)	Continuous	Continuous

	H Package	N Package
Power Dissipation (Note 12)	(Note 5)	670 mW
T_j max	150˚C	115˚C
θ_{jA} (Typical)	152˚C/W	115˚C/W
Operating Temp. Range	(Note 6)	(Note 6)
Storage Temp. Range	−65˚C≤T_A≤150˚C	−65˚C≤T_A≤150˚C
Lead Temp. (Soldering, 10 sec.)	260˚C	260˚C
ESD Tolerance (Note 13)	1700V	1700V

DC Electrical Characteristics

(Note 7)

Symbol	Parameter	Conditions		LF412A			LF412			Units
				Min	Typ	Max	Min	Typ	Max	
V_{OS}	Input Offset Voltage	R_S=10 kΩ, T_A=25˚C			0.5	1.0		1.0	3.0	mV
$\Delta V_{OS}/\Delta T$	Average TC of Input Offset Voltage	R_S=10 kΩ (Note 8)			7	10		7	20	μV/˚C
I_{OS}	Input Offset Current	V_S=±15V (Notes 7, 9)	T_j=25˚C		25	100		25	100	pA
			T_j=70˚C			2			2	nA
			T_j=125˚C			25			25	nA
I_B	Input Bias Current	V_S=±15V (Notes 7, 9)	T_j=25˚C		50	200		50	200	pA
			T_j=70˚C			4			4	nA
			T_j=125˚C			50			50	nA
R_{IN}	Input Resistance	T_j=25˚C			10^{12}			10^{12}		Ω
A_{VOL}	Large Signal Voltage Gain	V_S=±15V, V_O=±10V, R_L=2k, T_A=25˚C		50	200		25	200		V/mV
		Over Temperature		25	200		15	200		V/mV
V_O	Output Voltage Swing	V_S=±15V, R_L=10k		±12	±13.5		±12	±13.5		V
V_{CM}	Input Common-Mode Voltage Range			±16	+19.5		±11	+14.5		V
					−16.5			−11.5		V
CMRR	Common-Mode Rejection Ratio	R_S≤10k		80	100		70	100		dB
PSRR	Supply Voltage Rejection Ratio	(Note 10)		80	100		70	100		dB
I_S	Supply Current	V_O = 0V, R_L = ∞			3.6	5.6		3.6	6.5	mA

Note 2: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

AC Electrical Characteristics

(Note 7)

Symbol	Parameter	Conditions	LF412A			LF412			Units
			Min	Typ	Max	Min	Typ	Max	
	Amplifier to Amplifier Coupling	T_A=25˚C, f=1 Hz-20 kHz (Input Referred)		−120			−120		dB
SR	Slew Rate	V_S=±15V, T_A=25˚C	10	15		8	15		V/μs
GBW	Gain-Bandwidth Product	V_S=±15V, T_A=25˚C	3	4		2.7	4		MHz

AC Electrical Characteristics (Continued)

(Note 7)

Symbol	Parameter	Conditions	LF412A			LF412			Units
			Min	Typ	Max	Min	Typ	Max	
THD	Total Harmonic Dist	A_V=+10, R_L=10k, V_O=20 Vp-p, BW=20 Hz-20 kHz		≤0.02			≤0.02		%
e_n	Equivalent Input Noise Voltage	T_A=25˚C, R_S=100Ω, f=1 kHz		25			25		$nV/\sqrt{Hz}$
i_n	Equivalent Input Noise Current	T_A=25˚C, f=1 kHz		0.01			0.01		$pA/\sqrt{Hz}$

Note 3: Unless otherwise specified the absolute maximum negative input voltage is equal to the negative power supply voltage.

Note 4: Any of the amplifier outputs can be shorted to ground indefintely, however, more than one should not be simultaneously shorted as the maximum junction temperature will be exceeded.

Note 5: For operating at elevated temperature, these devices must be derated based on a thermal resistance of θ_{jA}.

Note 6: These devices are available in both the commercial temperature range 0˚C≤T_A≤70˚C and the military temperature range −55˚C≤T_A≤125˚C. The temperature range is designated by the position just before the package type in the device number. A "C" indicates the commercial temperature range and an "M" indicates the military temperature range. The military temperature range is available in "H" package only. In all cases the maximum operating temperature is limited by internal junction temperature T_j max.

Note 7: Unless otherwise specified, the specifications apply over the full temperature range and for V_S=±20V for the LF412A and for V_S=±15V for the LF412. V_{OS}, I_B, and I_{OS} are measured at V_{CM}=0.

Note 8: The LF412A is 100% tested to this specification. The LF412 is sample tested on a per amplifier basis to insure at least 85% of the amplifiers meet this specification.

Note 9: The input bias currents are junction leakage currents which approximately double for every 10˚C increase in the junction temperature, T_j. Due to limited production test time, the input bias currents measured are correlated to junction temperature. In normal operation the junction temperature rises above the ambient temperature as a result of internal power dissipation, P_D. T_j=T_A+θ_{jA} P_D where θ_{jA} is the thermal resistance from junction to ambient. Use of a heat sink is recommended if input bias current is to be kept to a minimum.

Note 10: Supply voltage rejection ratio is measured for both supply magnitudes increasing or decreasing simultaneously in accordance with common practice. V_S = ±6V to ±15V.

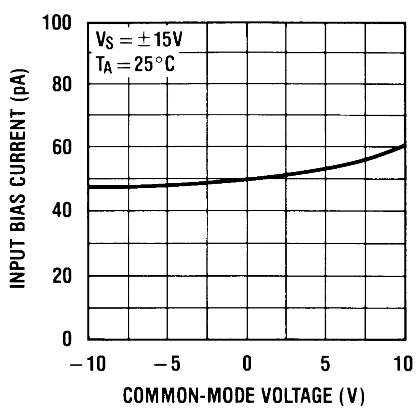
Note 11: Refer to RETS412X for LF412MH and LF412MJ military specifications.

Note 12: Max. Power Dissipation is defined by the package characteristics. Operating the part near the Max. Power Dissipation may cause the part to operate outside guaranteed limits.

Note 13: Human body model, 1.5 kΩ in series with 100 pF.

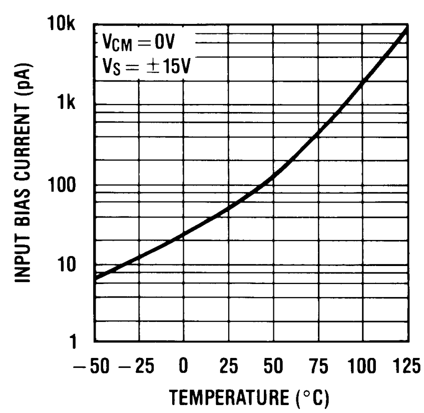
Typical Performance Characteristics

Input Bias Current



00565610

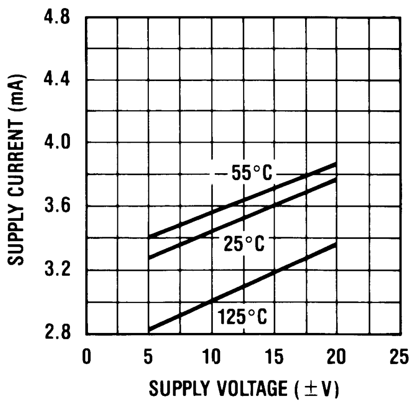
Input Bias Current



00565611

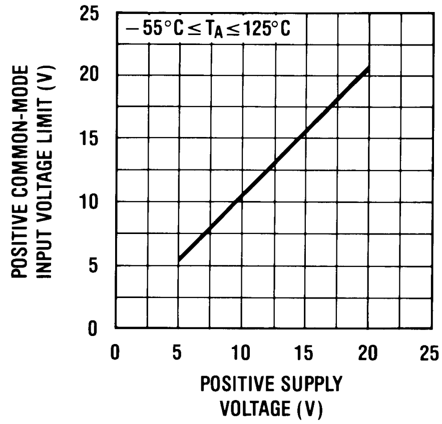
Typical Performance Characteristics (Continued)

Supply Current



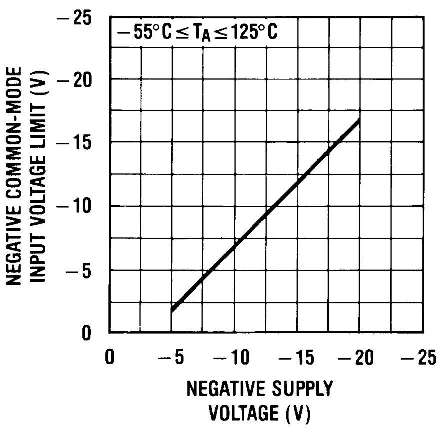
00565612

Positive Common-Mode Input Voltage Limit



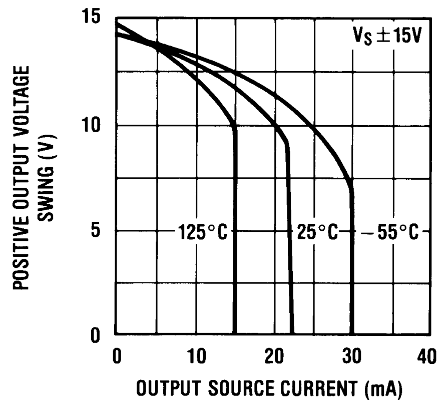
00565613

Negative Common-Mode Input Voltage Limit



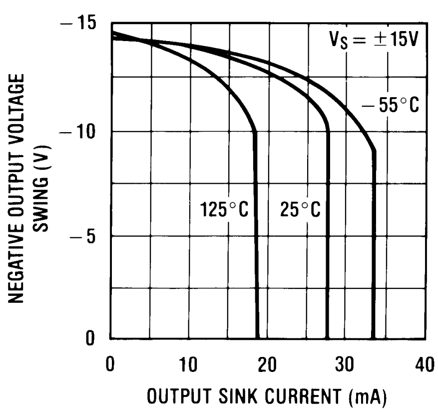
00565614

Positive Current Limit



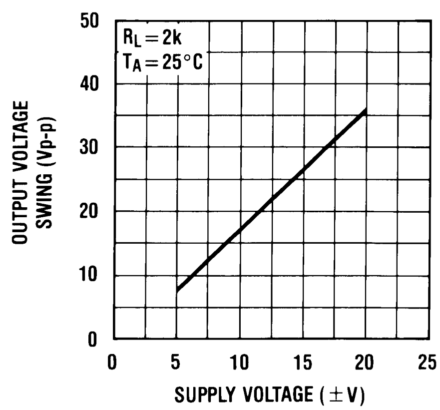
00565615

Negative Current Limit



00565616

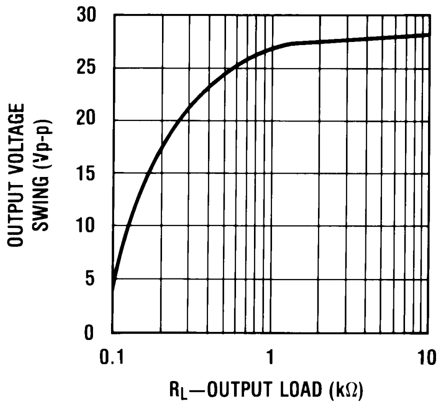
Output Voltage Swing



00565617

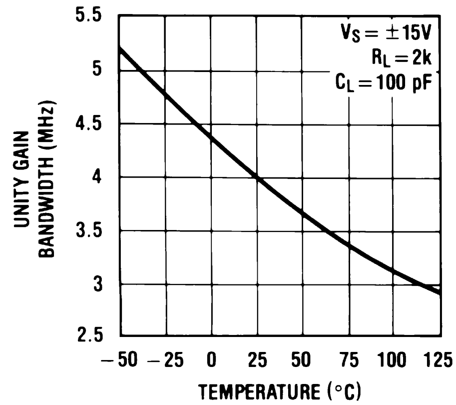
Typical Performance Characteristics (Continued)

Output Voltage Swing



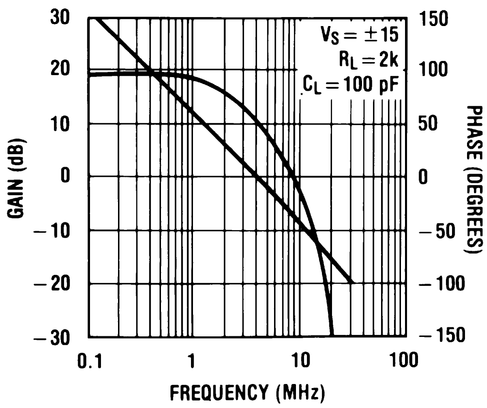
00565618

Gain Bandwidth



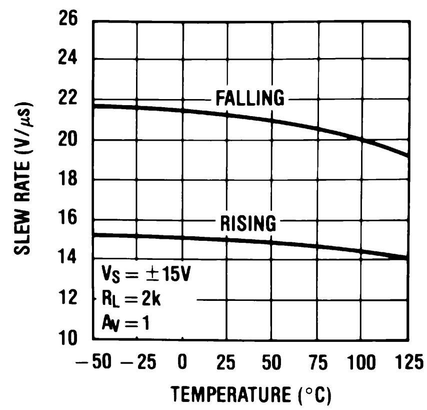
00565619

Bode Plot



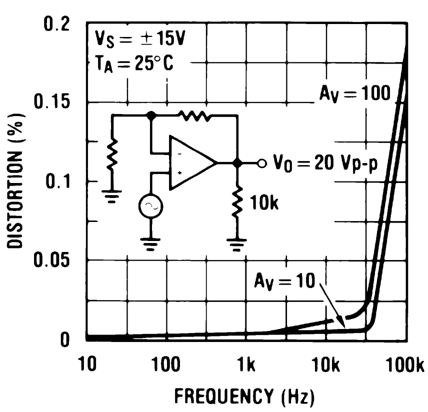
00565620

Slew Rate



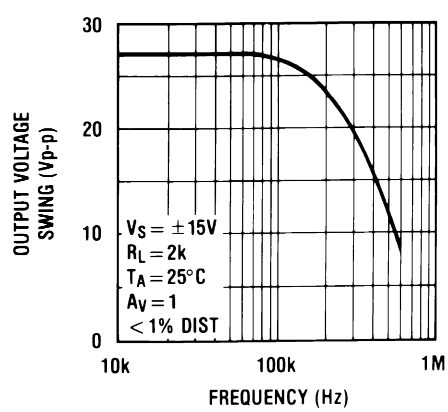
00565621

Distortion vs Frequency



00565622

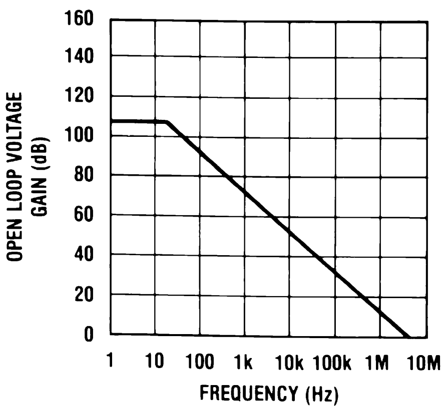
Undistorted Output Voltage Swing



00565623

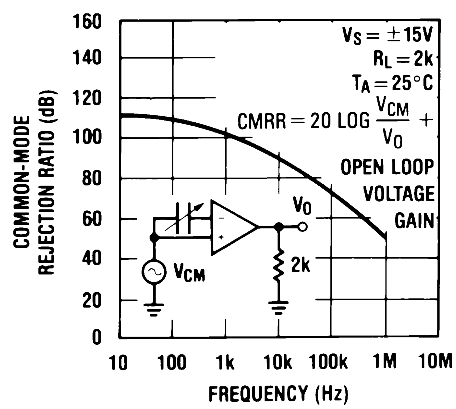
Typical Performance Characteristics (Continued)

Open Loop Frequency Response



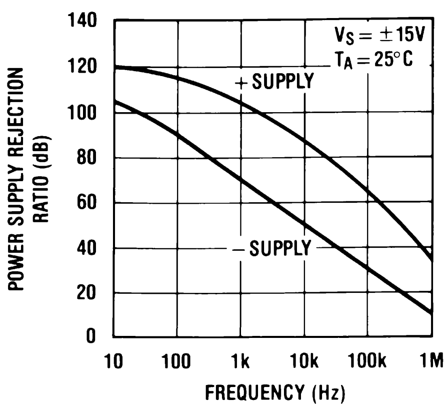
00565624

Common-Mode Rejection Ratio



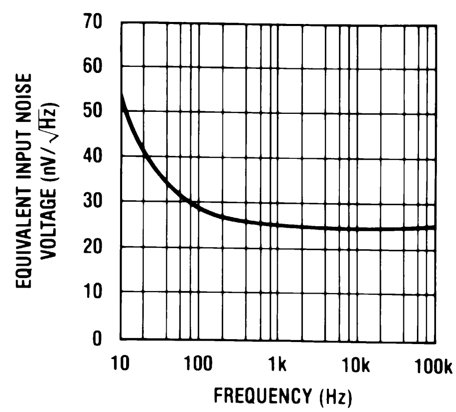
00565625

Power Supply Rejection Ratio



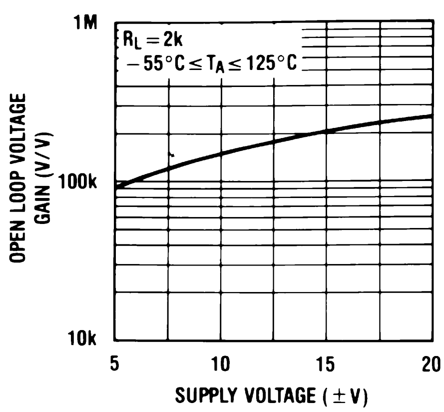
00565626

Equivalent Input Noise Voltage



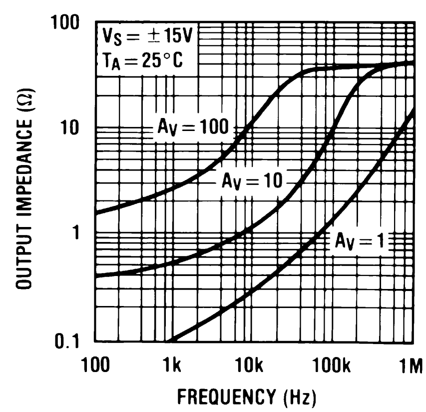
00565627

Open Loop Voltage Gain



00565628

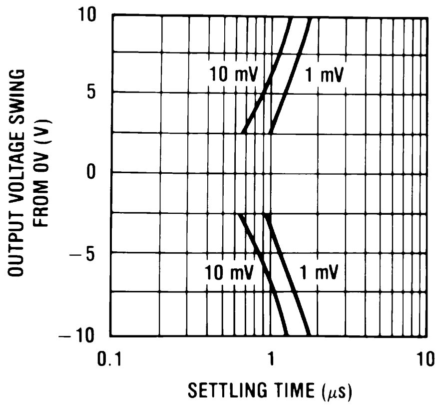
Output Impedance



00565629

Typical Performance Characteristics (Continued)

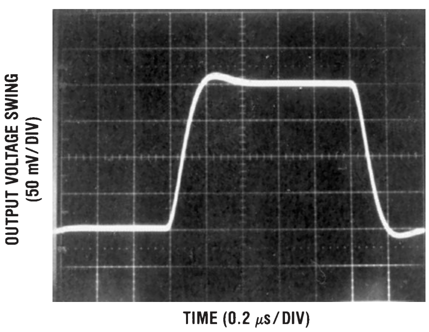
Inverter Settling Time



00565630

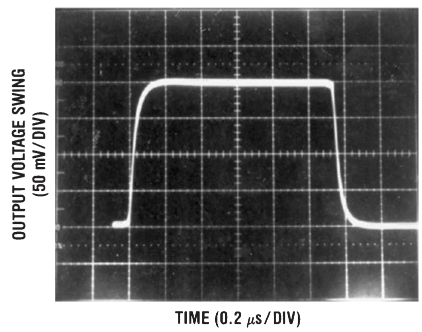
Pulse Response R_L=2 kΩ, C_L=10 pF

Small Signal Inverting



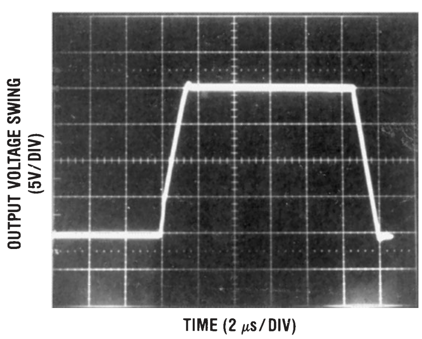
00565636

Small Signal Non-Inverting



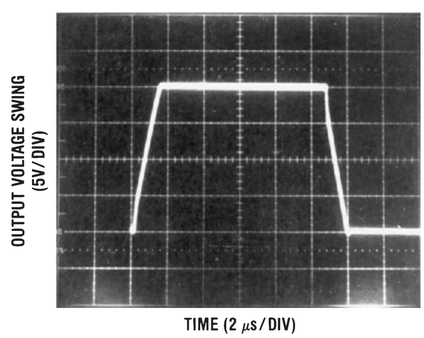
00565637

Large Signal Inverting



00565638

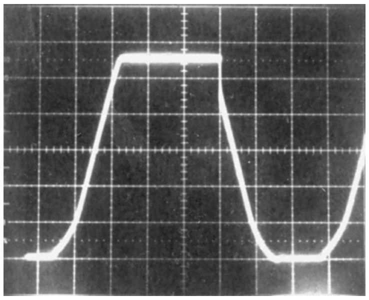
Large Signal Non-Inverting



00565639

Pulse Response R_L=2 kΩ, C_L=10 pF (Continued)

Current Limit (R_L=100Ω)



00565640

Application Hints

The LF412 series of JFET input dual op amps are internally trimmed (BI-FET II™) providing very low input offset voltages and guaranteed input offset voltage drift. These JFETs have large reverse breakdown voltages from gate to source and drain eliminating the need for clamps across the inputs. Therefore, large differential input voltages can easily be accommodated without a large increase in input current. The maximum differential input voltage is independent of the supply voltages. However, neither of the input voltages should be allowed to exceed the negative supply as this will cause large currents to flow which can result in a destroyed unit.

Exceeding the negative common-mode limit on either input will cause a reversal of the phase to the output and force the amplifier output to the corresponding high or low state.

Exceeding the negative common-mode limit on both inputs will force the amplifier output to a high state. In neither case does a latch occur since raising the input back within the common-mode range again puts the input stage and thus the amplifier in a normal operating mode.

Exceeding the positive common-mode limit on a single input will not change the phase of the output, however, if both inputs exceed the limit, the output of the amplifier may be forced to a high state.

The amplifiers will operate with a common-mode input voltage equal to the positive supply; however, the gain bandwidth and slew rate may be decreased in this condition. When the negative common-mode voltage swings to within 3V of the negative supply, an increase in input offset voltage may occur.

Each amplifier is individually biased by a zener reference which allows normal circuit operation on ±6.0V power supplies. Supply voltages less than these may result in lower gain bandwidth and slew rate.

The amplifiers will drive a 2 kΩ load resistance to ±10V over the full temperature range. If the amplifier is forced to drive heavier load currents, however, an increase in input offset voltage may occur on the negative voltage swing and finally reach an active current limit on both positive and negative swings.

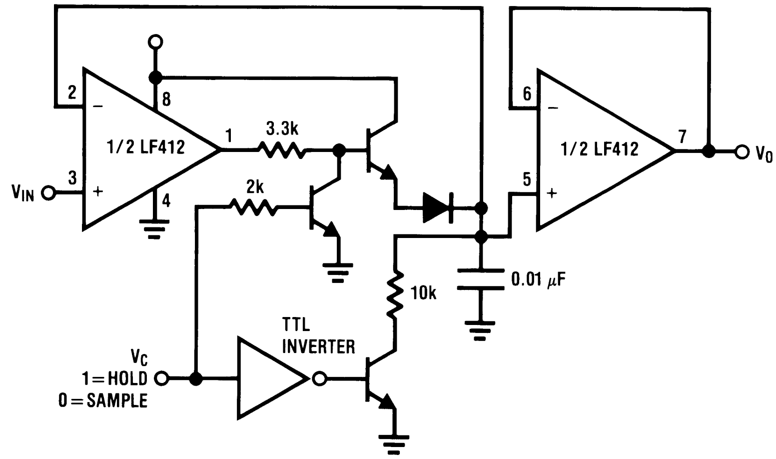
Precautions should be taken to ensure that the power supply for the integrated circuit never becomes reversed in polarity or that the unit is not inadvertently installed backwards in a socket as an unlimited current surge through the resulting forward diode within the IC could cause fusing of the internal conductors and result in a destroyed unit.

As with most amplifiers, care should be taken with lead dress, component placement and supply decoupling in order to ensure stability. For example, resistors from the output to an input should be placed with the body close to the input to minimize “pick-up” and maximize the frequency of the feedback pole by minimizing the capacitance from the input to ground.

A feedback pole is created when the feedback around any amplifier is resistive. The parallel resistance and capacitance from the input of the device (usually the inverting input) to AC ground set the frequency of the pole. In many instances the frequency of this pole is much greater than the expected 3 dB frequency of the closed loop gain and consequently there is negligible effect on stability margin. However, if the feedback pole is less than approximately 6 times the expected 3 dB frequency a lead capacitor should be placed from the output to the input of the op amp. The value of the added capacitor should be such that the RC time constant of this capacitor and the resistance it parallels is greater than or equal to the original feedback pole time constant.

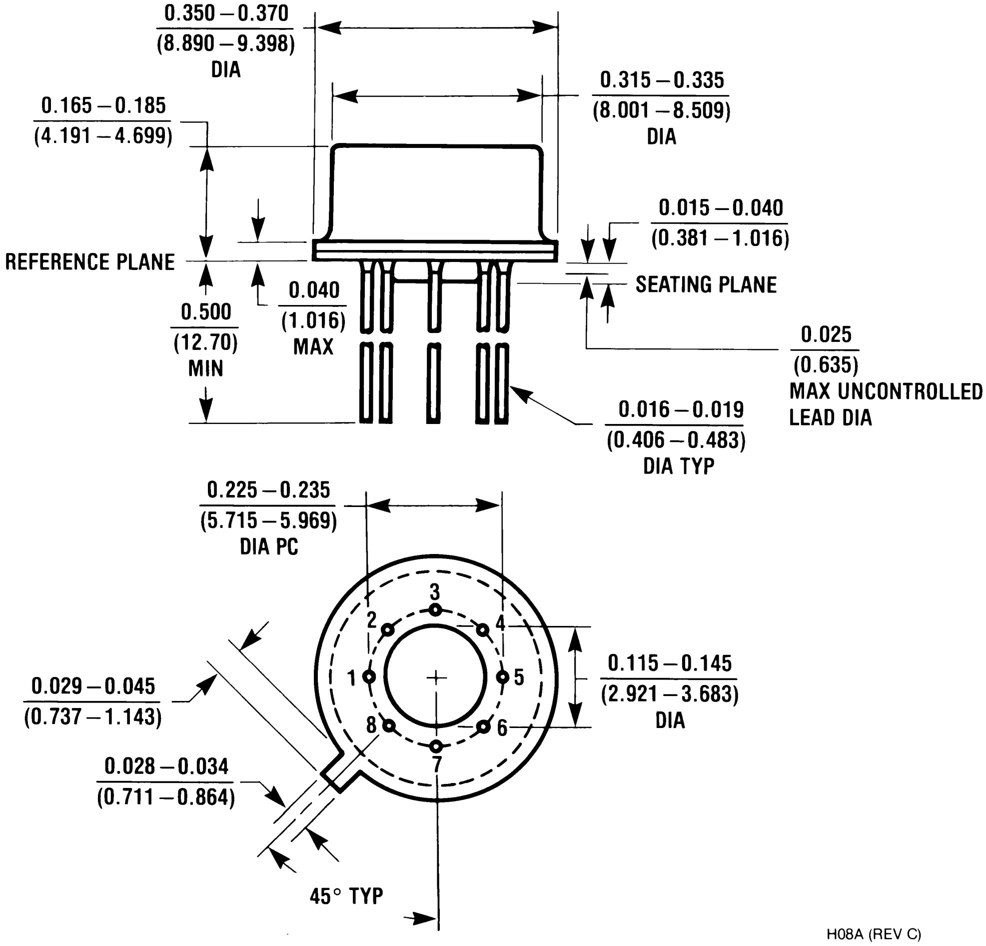
Typical Application

Single Supply Sample and Hold



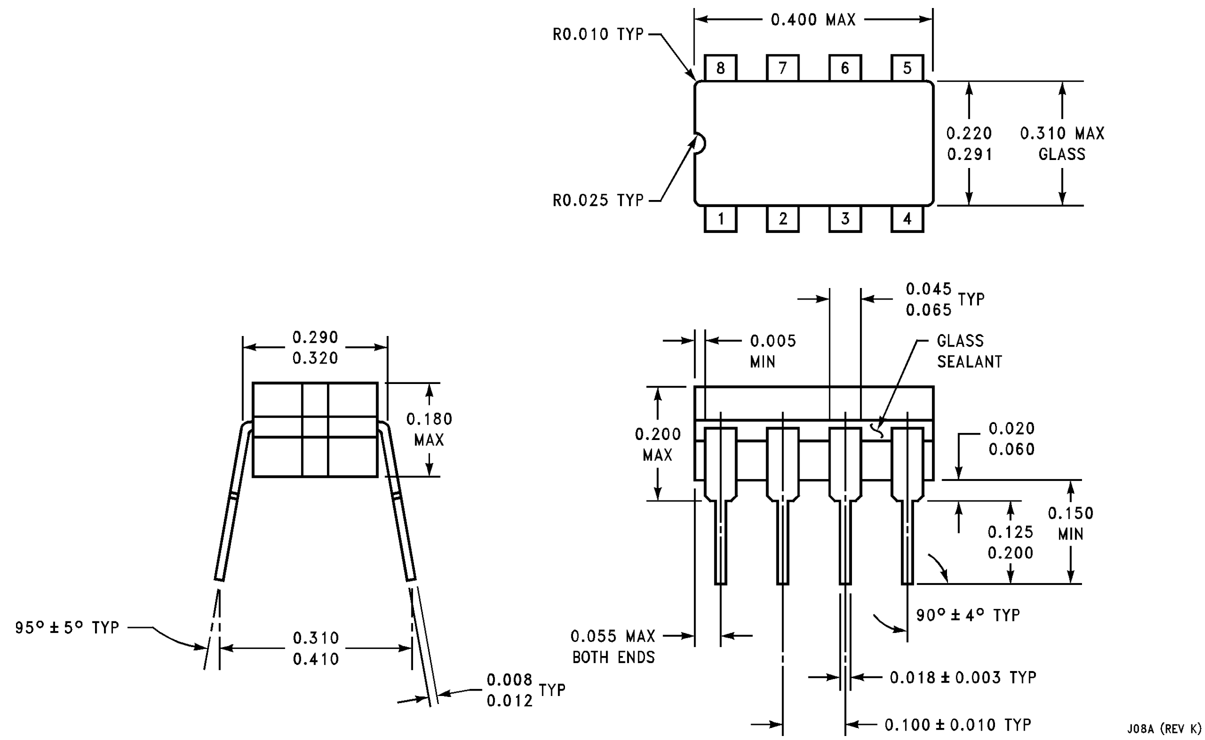
00565631

Physical Dimensions inches (millimeters) unless otherwise noted

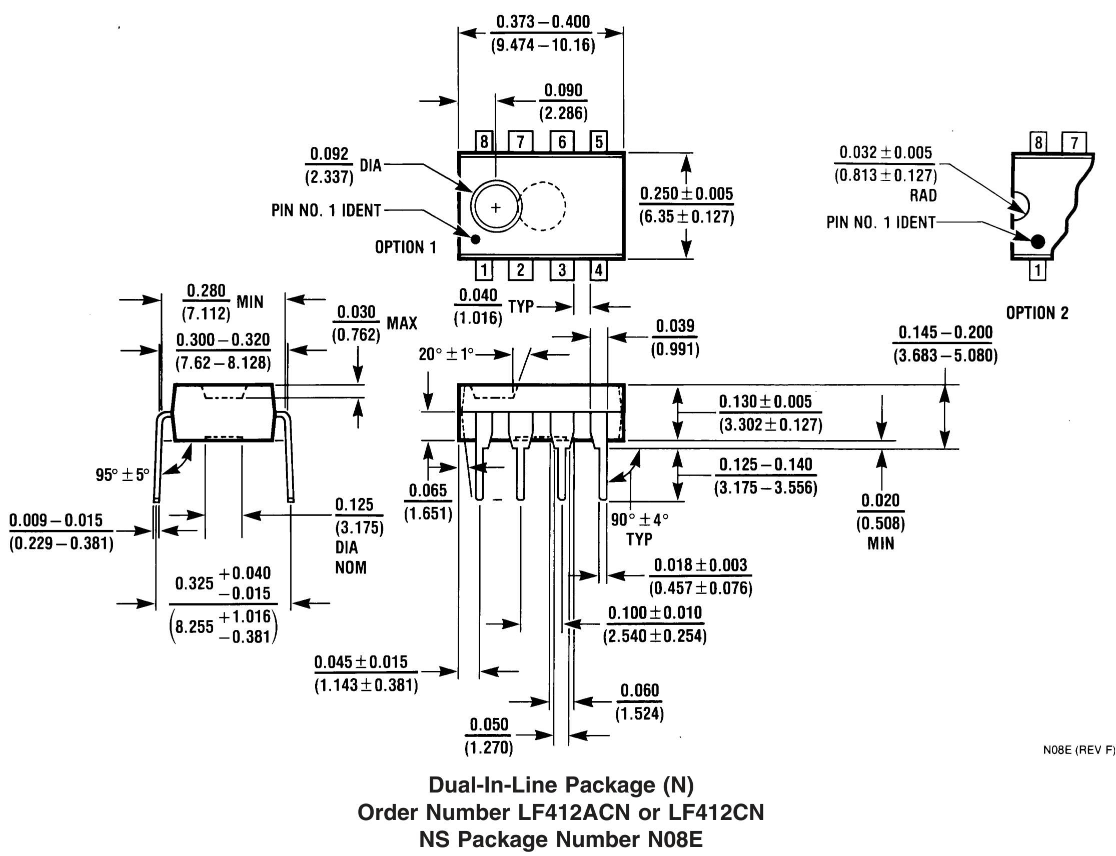


Metal Can Package (H)
Order Number LF412MH, LF412MH/883 or LF412CH
NS Package Number H08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Dual-In-Line Package (J)
Order Number LF412MJ/883
NS Package Number J08A



Dual-In-Line Package (N)
Order Number LF412ACN or LF412CN
NS Package Number N08E

Notes

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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